Subject to Revision.

[TRANSACTIONS OF THE AMERICAN INSTITUTE OF MINING ENGINEERS.

NOTES ON THE EXCAVATION OF THE NEW CROTON AQUEDUCT.

BY J. P. CARSON, NEW YORK CITY.

(New York Meeting, September, 1890.)

THE Croton water-shed furnishes the source and storage of water-supply to both the old and the new aqueduct. The Croton river rises in the southern part of Dutchess county, about 68 miles from the lower end of New York city. Its three main branches, called the East, Middle and West branches, flow southward across Putnam county, joining, near its southern boundary, to form the Croton, which continues thence in a general southwest direction across Westchester county to the Hudson river at Croton Point, about 35 miles north of the city. The water-shed above the proposed site of the Quaker Bridge dam extends about 33 miles north and south, with an average width of 11 miles, making in all about 367 square miles, from which, by complete storage, an average daily supply of 250,000,000 gallons may be collected—sufficient for the needs of the city, probably, for the next fifteen years. The water-shed above the Croton dam is 28 square miles smaller, and furnishes the present daily supply of 100,000,000 gallons.

By referring to the map it will be seen that the shortest approximately straight line between the proposed site of Quaker Bridge dam on the Croton and High Bridge on the Harlem river passes for the greater part down the valley of the Hudson. It was at first contemplated to construct the aqueduct in open cut, but investigation showed that the deep cuttings required would cost as much as a tunnel. This fact, and the consideration of the more permanent character of the work, caused the tunnel to be adopted. Although the line down the Hudson was the shortest, questions of land-damages arose, so that it was decided to to go further back from the river, where land was cheaper, and at the same time the necessary blow-offs could be easily constructed. After much deliberation, the location of the present line was adopted, commencing at Croton dam and running down the Saw Mill valley to High Bridge.

Fig. 1 shows the line of the aqueduct, and Fig. 2 its profile. The following data from the hand-book of information of the chief engineer give a digest of the extent and general features of the work.

Total area of water-shed of Croton river above Croton dam = 216,845 acres, or 338.82 square miles.

Total area of water-shed of Croton river above Quaker Bridge = 231,565 acres, or 361.82 square miles.

RESERVOIRS.

Now Existing.

	Contents in million gallons.	Height of dam in feet.	Length of dam in feet.	Elevation of crest of dam.
Croton Dam Reservoir, . .	2,000	50	270	167
Boyd's Corners Reservoir, on West Branch of Croton river,	2,700	78*	670	600
Middle Branch Reservoir, .	4,000	88†	980	380

Now Being Constructed.

	Contents in million gallons.	Height of dam in feet.	Length of dam in feet.	Elevation of crest of dam.
Double Reservoir "I," consisting of Sodom Dam Reservoir, East Branch of Croton river and Bog Brook Reservoir,	9,000	78	500	415

Proposed.

	Contents in million gallons.	Height of dam in feet.	Length of dam in feet.	Elevation of crest of dam.
Reservoir "A," on Muscoot river,	7,000	90‡	1400	410
Reservoir "D," on West Branch of Croton river,	9,000			
Reservoir "M," on Titicus river,	6,000	100	1200	325
Quaker Bridge Reservoir, on the Croton river,	30,000	264	1500	200
Total, ...	69,700			

DIMENSIONS OF AQUEDUCT.

	Feet.	Miles.
Total length of tunnel not under pressure (horse-shoe), . .	120,370.6	22.80
Total length of tunnel under pressure (circular), ...	36,079.8	6.83
Total tunnel, including syphon at Gould's Swamp, ...	156,450.4	29.63
Total length of aqueduct in open trench, ...	5,926.7	1.12
Total of aqueduct from Croton Lake gate-house to One-hundred-and-thirty-fifth Street gate-house, ...	162,377.1	30.75
Total length of pipe-line, ...	12,516.0	2.37
Total length from Croton Lake gate-house to Central Park gate-house, ...	174,893.1	33.12

* Fifty-six feet from bottom of pipe to overflow.

† Sixty-three feet from bottom of tunnels to top of overflow.

‡ Seventy-five feet from bottom of tunnels to top of overflow.

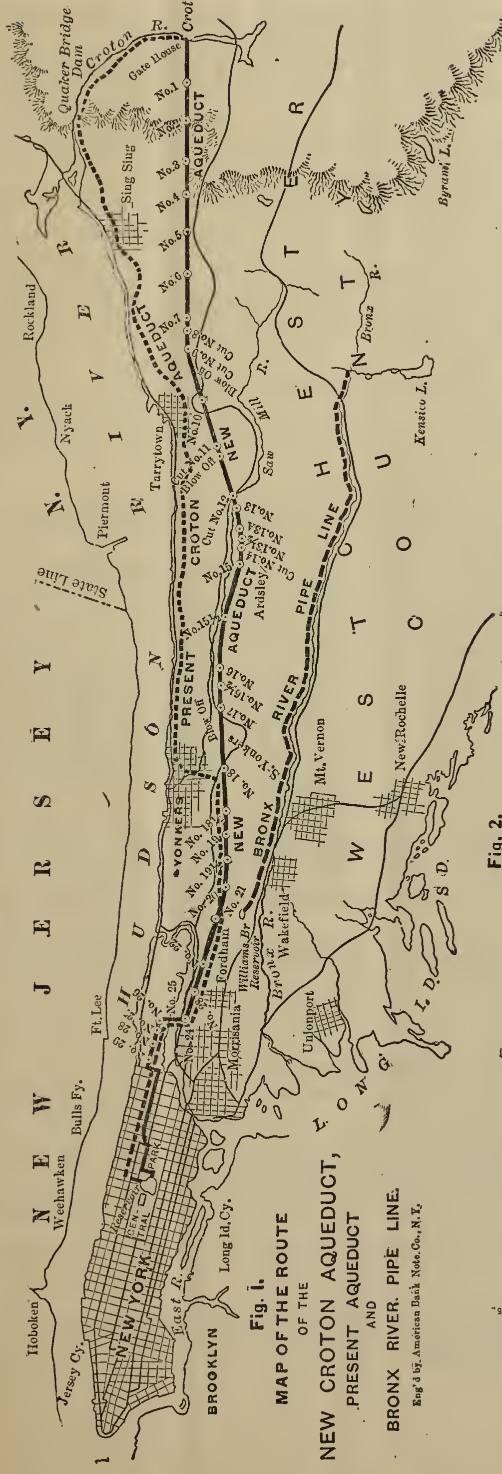


Fig. 1.

MAP OF THE ROUTE OF THE NEW CROTON AQUEDUCT, PRESENT AQUEDUCT AND BRONX RIVER. PIPE LINE.

Eng'd by American Bank Note. Co., N.Y.

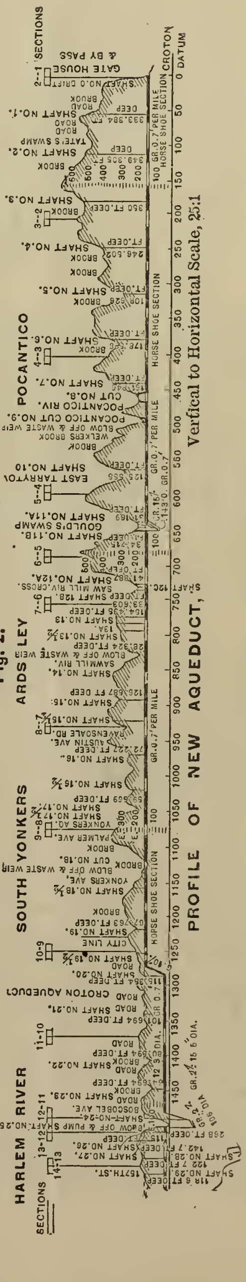


Fig. 2.

PROFILE OF NEW AQUEDUCT, Vertical to Horizontal Scale, 25:1

Map and Profile of the New York Aqueduct.

Total fall from Croton gate-house (elevation, 153) to One-hundred-and-thirty-fifth Street gate-house (elevation of water, 128), 25 feet.

Total fall from Croton gate-house (elevation, 153) to Central Park reservoir (elevation, 118.61), 34.39 feet.

Aqueduct under Harlem River.

Depth of center-line below mean high water, 307 feet.

Maximum inward pressure on aqueduct when empty, 128.74 lbs. per square inch.

Maximum pressure on aqueduct when full, 55.29 lbs. per square inch.

Horse-shoe shape: height, 13 feet $6\frac{36}{100}$ inches; width, 13 feet $7\frac{20}{100}$ inches; inside area, 155.573 square feet = a circle 14 feet 1 inch in diameter.

Prevailing circular shape: diameter, 12 feet 3 inches; inside area, 117.86 square feet.

Circular shape under Gould's swamp: diameter, 14 feet 3 inches; inside area, 159.48 square feet.

Circular shape under Harlem river: diameter, 10 feet 6 inches; inside area, 86.59 square feet.

Flowing capacity of aqueduct above Shaft No. 20 (not under pressure), 318,000,000 gallons per twenty-four hours.

Flowing capacity of aqueduct below Shaft No. 20 (under pressure), 250,000,000 gallons per twenty-four hours.

NOTE.—Difference, 68,000,000 gallons, expected to be distributed in annexed district through a proposed intermediate reservoir.

Flowing capacity of pipe-line (8 pipes of 48 inches diameter each) from 135th Street gate-house, 250,000,000 gallons (approximated) per twenty-four hours.

NOTE.—Four of these pipes deliver 125,000,000 gallons into the Central Park Park Reservoir; the balance of 125.000,000 gallons is taken into city distribution through the other four pipes.

Gate-Houses.

Croton Lake gate-house.—Built in view of the construction of the Quaker Bridge dam.

One-Hundred-and-Thirty-fifth Street gate-house.—At end of the aqueduct and beginning of the pipe line.

Central Park gate-house.—At the end of the pipe-line and at the head of Central Park reservoir.

Blow-offs.

Pocantico blow-off, distance from Croton gate-house, $9\frac{29}{100}$ miles; empties into Pocantico river and Hudson river through Sing Sing.

Ardsley blow-off, distance from Croton gate-house, $15\frac{65}{100}$ miles; empties into Saw Mill river through Yonkers.

South Yonkers blow-off, distance from Croton gate-house, $21\frac{15}{100}$: empties into Tibbett's brook and Harlem river through Van Courtland lake.

Shaft No. 25, distance from Croton gate-house, $28\frac{38}{100}$ miles; empties into Harlem river.

Overflow at Shaft No. 26, distance from Croton gate-house, $28\frac{48}{100}$ miles; empties into Harlem river.

Total number of principal shafts, 32; total number of auxiliary shafts, 10; total number of shafts to be left open, 28.

Deepest shaft is No. 25; depth, $419\frac{7}{10}$ feet. Shallowest shaft is No. $17\frac{1}{2}$; depth 22 feet. Average depth of shafts, $122\frac{1}{10}$ feet.

Total number of portals, 9.

Total number of open cuts, 6, as follows: Open cut 8A, length 84 feet; open cut 8B, length 733 feet; open cut 9, length 1312 feet; open cut 12, length 123 feet open cut 14, length $459\frac{2}{10}$ feet; open cut 18, length $3215\frac{4}{10}$ feet.

MISCELLANEOUS INFORMATION.

Brick-work.

The amount of brick-work laid in the New Croton Aqueduct is estimated at 312,258 cubic yards, or about 163,000,000 of bricks, which would build thirty-three structures the size of the *Tribune* building.

The total area of the inside surface of the aqueduct from Croton lake to One-hundred-and-thirty-fifth Street gate-house is equal to 7,092,823 square feet, or 162.83 acres, or about equal to $\frac{1}{5}$ the area of Central Park.

Excavated Material.

The total excavated material of the entire aqueduct exceeds 2,800,000 cubic yards.

The total excavated material plus the masonry placed exceeds 3,250,000 cubic yards. This is equivalent to 83 per cent. of the volume of the great pyramid of Cheops. This material would be sufficient to build a wall 10 feet thick and 55 feet high around Manhattan Island, 30 miles in length on the water front.

The amount of dynamite used in blasting on the aqueduct, exclusive of the amount used in sinking the shafts, was over 5,800,000 lbs., or over 2900 tons.

Elevations.

Maximum level of present Croton lake, . . .	167 feet.	
Level of water at One-hundred-and-thirty-fifth Street Gate House, ...	128 "	
Level of water at Central Park Gate House, . .	$118\frac{61}{100}$ "	(reservoir full).

All elevations are referred to the Croton datum, which is $3\frac{61}{100}$ feet below mean high water of Harlem river or city datum.

The flowing capacity of the aqueduct, 318,000,000 gallons per twenty-four hours, is equivalent to a stream 50 feet wide and 10 feet deep flowing 59.1 feet per minute, or about 1 foot per second, or about $\frac{7}{10}$ths of a mile per hour.

GEOLOGY.

The rocks are metamorphic, principally gneiss, which varies from firm granite to ordinary mica-schist. The first 14 miles from Croton dam to the crossing of the Saw Mill river are through this material, and it constitutes about 90 per cent. of all the rock passed through to Harlem river. The general strike is N. 20 E., and the dip varies from 20° to 85° E. It was generally observed that where a brook occurs on the surface the stratification of the rock below has undergone great disturbance. This is characterized by faults, a jointed

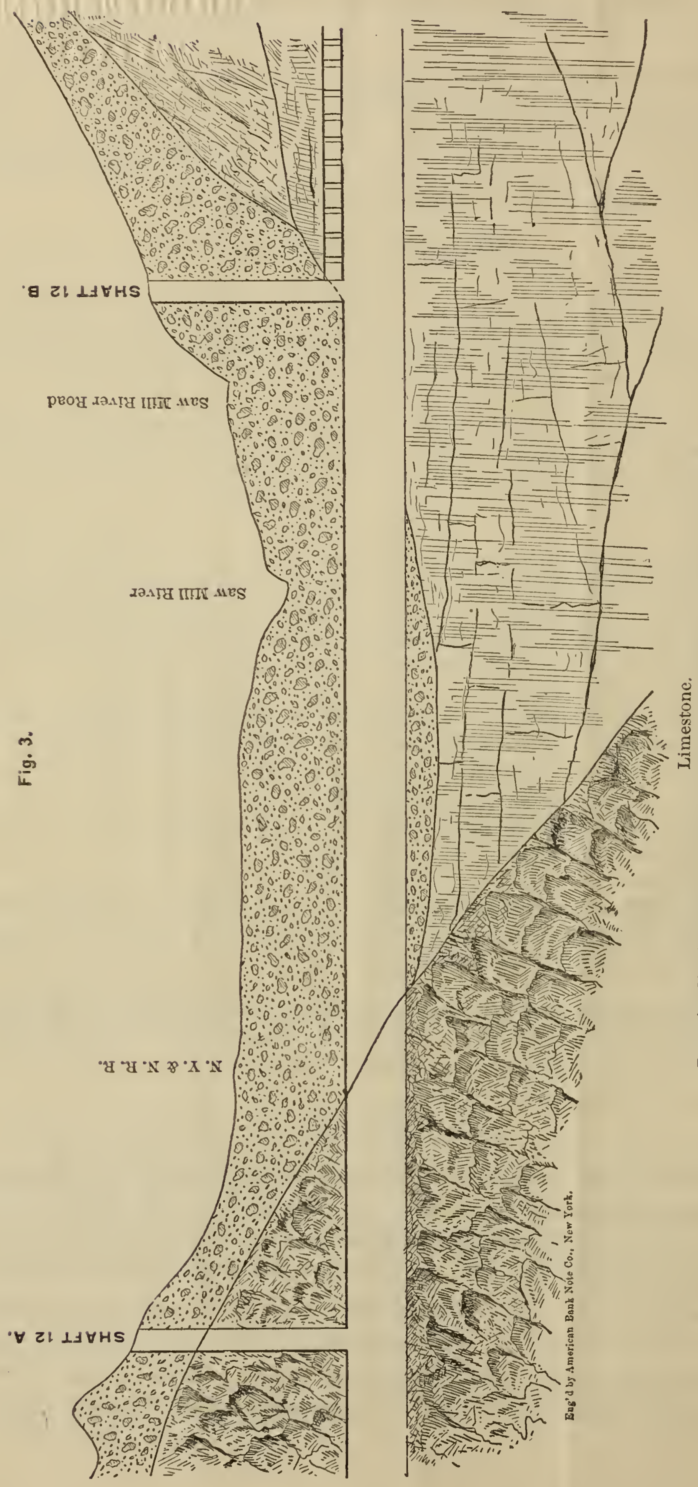


Fig. 3.

Longitudinal Section of Aqueduct from Shaft 12 A to Shaft 12 B.

structure, and seams of variable size filled with talc, decomposing feldspar and clay. This faulty ground, after a few weeks' exposure to the air, is liable to fall down, by reason of the slacking or swelling of the seams.

The only interesting mineral specimens found were a few insignificant crystals of garnet and pyrite, and some fine pieces of fibrous asbestos—the latter in the tunnel under the Harlem river.

At the Saw Mill river first occurred a mass of siliceous dolomitic limestone, striking N. 46° E., and dipping 60° to 70° S.E. Near the surface it was decomposed, but gradually became harder, and for an occasional small pot-hole or clay-seam, continued quite regularly for 4200 feet. It then gradually became decomposed (260 feet) and finally the soft ground of No. 13 South was reached.

This extended practically for 110 feet, and the driving of the tunnel through it caused more anxiety, trouble, and expense, than any other similar work in this country. The predominant material was a hard, compressed, yellow mud, composed of fine particles of mica, sand and clay. Through the mass there were vugs of white and yellow clay, and several strong, water-bearing seams, filled with white sand and gravel. The water from these seams, when they were cut, formed with the mud a sticky mixture of the consistency of pea-soup. This mixture, being strained or allowed to settle, gave a sandy residue, upon which one could stand without sinking. A lump of the mud readily dried and hardened in the open air, but dissolved immediately in water. It was equivalent to a quicksand.

South of this pocket, the limestone again occurs for 2230 feet, then decomposed gneiss for 640 feet, then two small peaks of limestone, with irregular seams of feldspar, clay, and boulders, which, with a cave from the surface, caused some trouble. Then came two pockets of clay, each extending about 60 feet. At the southern limit, the limestone and gneiss merged into each other in wavy lines, without a distinct dividing seam.

This bed of limestone may be said to extend 6800 feet. It is to be regretted that the tunnel-notes on the dip and strike are not as complete as would be desirable.

Figs. 3, 4, and 5, are longitudinal sections on the line of the tunnel, and Fig. 6 is a cross-section taken in the excavation for the blow-off at Ardsley. The longitudinal sections south of Shaft 13 were determined by the diamond drill.

For the next 4.87 miles the rock is mica-schist, with the occasional jointed structure. Then, in Shaft 17, occurred for 265 feet a pocket

of sand and drift-boulders, with decomposed rock for 60 feet on either side. The distance below the surface was 150 feet.

For the next 3.39 miles, with the exception of 3200 feet of open-cut, the mica-schist is again found. The tunnel then approaches within 30 to 40 feet of the surface, and passes through 1730 feet of sand and boulders. It then soon follows down the incline and enters the gneiss, which, with the exception of a pear-shaped horse of greenstone, about 50 feet long, occurring at Shaft 20, continues 4.34 miles to the Harlem river.

Recapitulation: Croton Dam to Harlem River.

Gneiss,	25.54 miles.
Clay and limestone,	1.29 "
Sand,	0.38 "
Open-cut,	1.12 "
Total,	28.33 miles.

The Excavation.

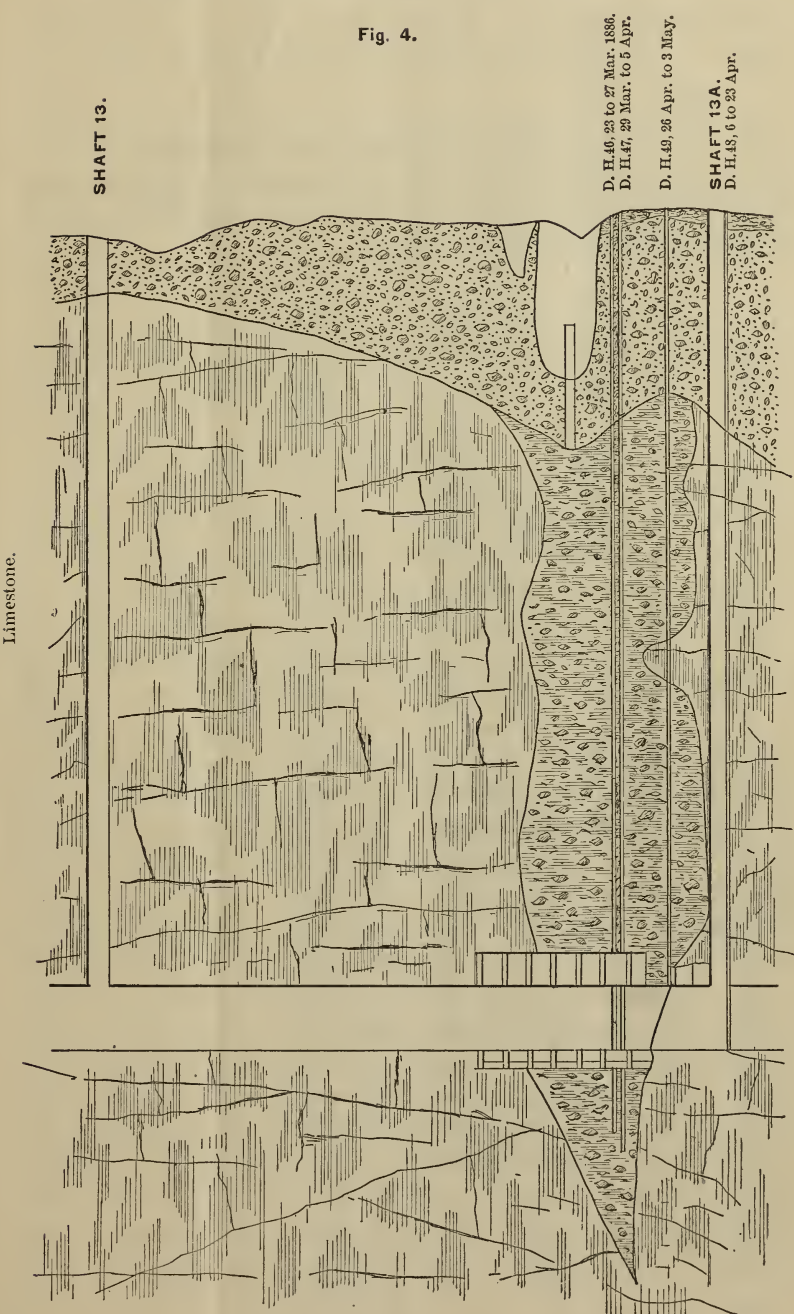
It was not contemplated to line the entire tunnel with brick, but the developments of the nature of the rock soon demonstrated the necessity for doing so. The contract-price for tunnel-excavation was $7 00 per cubic yard, or $52.88 per running foot. This included everything. But in case of excessive excavation, the vacant space between the rock and the brickwork was to be filled with broken stone packed dry, at the expense of the contractor.

After the order had been given to line the entire tunnel with brick, it was further ordered to fill the vacant space with rubble, built in radial lines, so as to strengthen the arch. The simple excavation then became complicated with the question of "making rubble," which was a very great opportunity for those who "would not play false, and yet would wrongly win."

The following notes are from personal observations, and data compiled from the records of Sections 7 and 8, Division 3.

The American center-cut system was used. The plant is described below. In driving the heading, the usual difficulty was experienced in keeping the floor at or about the grade of the spring-line. It invariably crept up one or two feet (the roof following suit); the reason given being that this was "on account of the drainage," or "on account of the very bad rock, which breaks high." The truth was that the frequency of drill-holes showed the rock to be very good. In practice the ordinary rock could be broken as desired by placing the drill-holes about a foot within the line.

Fig. 4.



Section showing Bad Ground near Shaft 13 A.

The area of the horse-shoe section with 12-inch lining was:

					Per cent.
Above spring-line,	73 sq. ft.	Average as excavated,	105 sq. ft.	Excess,	44
Below "	131 "	" "	178 "	"	35
Total,	204		283		38

The areas of the heading and bench as excavated are in the ratio of 3 : 5. The following table shows the average weekly progress and the proportion of time lost when working through different kinds of material, and by different methods:

TABLE I.

Average Weekly Progress of Tunnel on Division 3 as Worked by Different Systems through Different Materials.

Character of Material.	Heading and Bench Worked Together.							Heading Worked Alone.							Bench Worked Alone.						
	Number of working points.	Weeks worked.		Area square feet.	Linear feet.			Number of working points.	Weeks worked.		Area.	Linear feet.			Number of working points.	Weeks worked.		Area.	Linear feet.		
		Per cent. no progress.	Total.		Total.	Per week.	Cubic yards per week.		Per cent. no progress.	Total.		Total.	Per week.	Cubic yards per week.		Per cent. no progress.	Total.		Total.	Per week.	Cubic yards per week.
Soft ground, clay, sand and mica	2	28	128.	507.7	110	1.4*															
Sand and boulders	1	40	62.3	490.	265	4.25															
Decomposed rock, limestone, felspar and mica-schist	7	31	152.	361.	1,487	9.8	131.	1	12.5	8	165	188	23.5	143.6	2	42	19	196	230	12.1	87.7
Limestone	3	24	95.5	283.	2,148	22.4		3	13.4	52	105	1752	33.8		3	3	57	178	1531	27.	
Mica-schist	8	4.4	427.	283.	13,832	30.	314.	8	0.6	164	105	7711	47.	183.	8	2.4	247	178	8913	36.1	238.
								At foot of shaft.							At foot of shaft.						
								10	20	54		528	9.8		6	35	23		1.91	8.3	
															Sinking shaft.						
															7	5	98	200	658	6.7	49.1

* This figure is the average, not of the whole period, but of the last stage (and best practice).

In this table, the column headed "Per cent. no progress" shows the proportion of time during which the work stood still.

The Different Systems of Excavations Considered in Relation to the Subsequent Brickwork.

For 16 months, or until Sept. 1886, the headings and bench were worked together, being kept as near as possible (the average distance between them being about 50 to 75 feet) and the tunnels had advanced about 1500 feet from the shaft.

It was then decided to change this procedure and drive the headings first. This was done, by constructing an inclined plane about 400 feet long from the grade of the tunnel to the grade of the heading.

The following reasons were advanced:

1. Because progress was delayed by the difficulty of ventilation; whereas by first connecting the headings, the air would be improved and the work really advanced. This is in part true.

2. Transportation. Because of the length of haul, there was great difficulty in moving the "runs," and in getting rid of the broken stone. Moreover it was desirable to start the masonry. But in taking out the enlarged heading at once, both operations would be impeded.

3. As the rock from the heading was too much shattered to be used for rubble, it was most advantageous to leave the bench to be subsequently excavated, and thus to save the re-handling of the broken stone by using it directly for the masonry.

Under certain local conditions, these two latter reasons may be good, but a consideration of facts connected with this work will serve the double purpose of showing that they are not sound in regard to it and of illustrating the manner of conducting the work.

The "runs" were movable bars, placed across the tunnel, to support the continuation of the track from the heading, so that the muck could be directly dumped from the cars above to those below.* The transportation was done in cars holding about a cubic yard of broken stone, equivalent to half a yard of solid rock. One mule hauled two and sometimes three at a trip. Up to a distance of 1500 feet, 6 to 8 cars were allowed to each heading. It is easy to show that a third more would suffice for an increased haul up to 4500 feet, which was greater than ever occurred.

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*The labor is not increased on this account; hence it may be regarded as an incidental detail.

The average daily excavation of the bench and heading was 53 cubic yards of solid rock and of the bench alone 40 cubic yards. The transportation of this material would require trips of two cars, to be made respectively every 24 and 30 minutes. The relative difference of interruption was therefore practically the same in both cases.

The subsequent excavation of the bench involves the following questions:

1. The quantity of rubble required;
2. The rate of construction of the masonry; and
3. The rate of excavation of the bench.

1. *The Quantity of Rubble Required.*—The rock from the heading was too much shattered for use as rubble, and the same applies to about 25 per cent. of that from the bench.

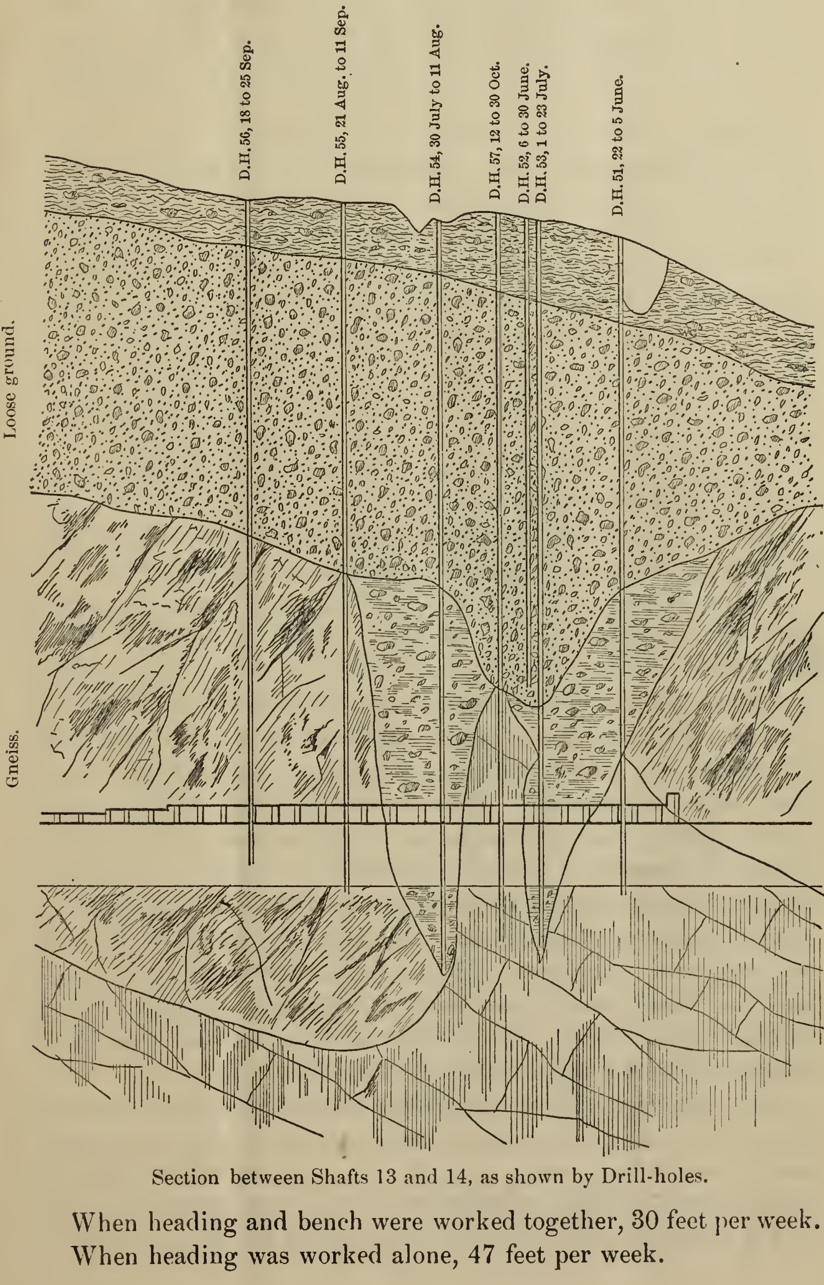
Requirements of Rubble.

	Average daily progress, feet.	Per running foot.	Cubic yards of Rubble used per day.
Side-walls, . . .	40	0.78	17
Arch, ...	20	1.43	29
Invert, ...		0.40	
Total, . . .		2.61	46
Bench, ...	6	6.6	40 = 64 broken.

The masonry was built in the above order, and required 1.74 cubic yards of solid rock per running foot. The bench contained 6.6 cubic yards, or after allowing for waste, sufficient for three (3) running feet of masonry. It would then appear proper to leave one-third of the bench in the tunnel to be used as needed. Often more than one-half was left. In practice the stone was used by the masons direct from the car—whenever possible—but even under the most favorable circumstances about a third more was daily excavated than could be so employed. The broken stone was piled up at a convenient place in the tunnel, about 7 feet high and 6 feet wide, a quantity about sufficient for one running foot of arch. It had to be rehandled; so that it would generally have been more convenient to have piled it on the surface. The cost of hoisting it to and lowering it from the surface was saved, which amounted to 17 cents per cubic yard, while the increased cost of working the heading and bench separately (supposing work in both tunnels) was, as will be subsequently shown, $2.10 per cubic yard.

2. *The Question of Time.*—By referring to Table I., it will be seen that with mica-schist the average progress was as follows:

Fig. 5.



Section between Shafts 13 and 14, as shown by Drill-holes.

When heading and bench were worked together, 30 feet per week.
When heading was worked alone, 47 feet per week.

When bench was worked alone, 36½ feet per week.

It therefore required 1.3 week to excavate a length of bench equal to the length of heading excavated in 1 week. Hence, 2.3 weeks were required to excavate 47 feet of complete enlarged tunnel-section. The weekly progress was therefore 20.43 feet, or 32 per cent. less, working separately, than when working together both heading and bench.

As the relative daily advance of the masonry to the excavation (done separately) was as 20 to 3.4, obviously one would overtake the other and would have to stop. So no time was saved by rushing the masonry, as its completion was limited by that of the excavation.

The tunnel and brickwork can be finished practically at the same time, without delay to either: *first*, by carrying on the brickwork without rushing, at a reasonable distance behind the excavation, say 500 feet, and at the same rate of advance, say 5 feet per day; *second*, by starting the brickwork after 80 per cent. of the excavation is completed, and continuing the excavation of the full section.

By excavating the heading and bench separately, the time for the completion of the work is increased 10 per cent.

At Shaft 15, out of 7000 feet in length, 3400 feet or 49 per cent. of heading and bench were excavated separately.

The lower portion of the aqueduct, Shaft 11 B, Station 687 + 00, to Shaft 24, Station 1489 + 88, after deducting 3798 feet of open-cut, consisted of 76,490 feet of tunnel. Of this, 18,026 feet of heading and bench were excavated separately—or 23 per cent. The delay was 11.5 per cent.; but as both headings were frequently not driven at the same time, this percentage should be doubled, and, from the fact that some shafts were idle for over two months, the excavation was completed in 45 months instead of 33, the increase of time being 36 per cent. A part of this delay was reasonable, on account of the bad ground in Shaft 13, but there was no good cause why the work should have been delayed so long as 4 months after No. 13 was finished. The approximate increase of cost of driving heading and bench separately, as compared with driving them together, is shown in the transcripts from actual average practice, given at the close of this paper under "Cost of Driving."

One might infer from the foregoing, that the contractors were unmindful of their own interests—which, in the light of subsequent events, would be a great mistake. The most probable reason of their choice of method was that there was not sufficient boiler-power, and they did not wish to incur the expense of further additions.

To each shaft there were two tubular boilers, 75 horse-power. As many of these boilers had been burned out soon after the work started, their actual power was probably reduced to about 60 horse-power. As the work advanced, this power was not sufficient; the ventilation became fouler, and the receipts consequently fell off; to keep them up, the sub-contractors were forced to start the masonry, and rush it regardless of all principle.

On the northern portion of the work, from station 0 to 687 + 00, the length of the tunnel was, after deducting the open-cuts, 66,571 feet. Of this, 3550 feet of bench and 2030 feet of heading were driven separately, or 8 per cent. of the whole tunnel, as against 23 per cent. done in this way on the southern portion. The reason is, that the work was not sub-let, the management was concentrated, and it was cheaper to drive the full section.

Ventilation and Lighting.

The Lighting.—For the first two years, gasoline torches, miners' lamps, a few candles, and electric lights to some extent, were used. The two former predominated. The air finally became so foul, that an order was issued forbidding the use of torches or lamps, and after a time the torches were abandoned. In the construction of the masonry only candles and the electric light were employed.

The Means of Ventilation.—On the northern portion of the work, the arrangement for improving the ventilation was by means of what the men termed, very properly, "smoke-boxes." These consisted of wooden flues, varying in section from 10 inches by 24 inches to 18 inches by 36 inches, placed continuously along the side on the floor of the tunnel. They were too small. They should have been air-tight, but they were continuously being broken or damaged by falling stones and other accidents. Air-jets were inserted at intervals, which had a cooling and consequently detrimental effect. The automatic action of the flue depends upon the difference of density between the interior and external air of the tunnel. As the average temperature inside was about 60°, the desired action could only occur during a few months of winter when the outside temperature was low. Had a sufficiently large flue been placed along the roof and connected with a fire-place, the arrangement, though clumsy and expensive, would have been rational, whereas the system as employed was a miserable farce.

For the ventilation of the southern portion, Baker blowers No. 4½ were used. They were run by independent 10 horse-power engines

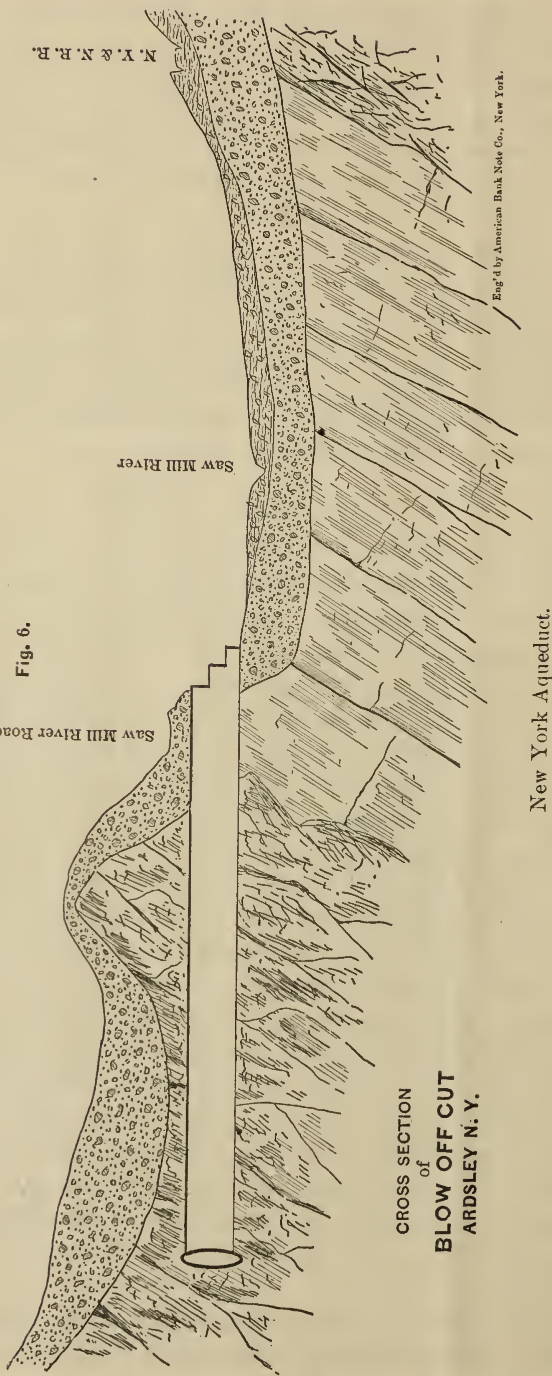

N. Y. & N. R. R.
Saw Mill River
Saw Mill River Road
New York Aqueduct.
CROSS SECTION
of
BLOW OFF CUT
ARDSLEY N. Y.
Eng'd by American Bank Note Co., New York.

Fig. 6.

at from 70 to 150 revolutions per minute—80 revolutions being a fair average. According to the manufacturers' circular, the capacity was $16\frac{1}{2}$ cubic feet per revolution. The air was conveyed by spirally-rivetted 12-inch iron pipe with ends fitting into each other, and suspended on the side of the tunnel about the spring-line. It was carried to within 100 or 200 feet of the blasting operation.

The air was usually forced. The reasons given for this procedure were that the men liked it better, and because the eccentric of the engine was set to work that way. At Shaft 24, however, a Sturtevant fan was arranged for both forcing and suction.

Shaft 16 was provided with two blowers, but they were seldom used, because it was considered too much trouble to keep the pipes in repair.

At Shaft 15, the volume of air delivered in each heading and the loss by leakage was as follows—the velocity being determined by a standard Casella anemometer:

Date.	Number of Experiments.	Distance from Blower. Feet.	Revolutions of Blower per minute.	Theoretical Volume. Cubic feet.	Actual Volume. Cubic feet.	Per cent. lost by friction and leaks.	Volume delivered to each heading. Cubic feet.
18–22 Dec., '86..........	7	2350	113	1854	942	54	471
7–21 March, '87...........	4	3000	113	1854	870	56	435
31 Mch. and 4 Apl., '87..	2	3400	110	1815	320	82	160
							355 Av'g.

To the above must be added the air from each drill, 65 cubic feet a minute; but as the drilling occupies but 7 hours, the average quantity delivered during the ten-hour shift is 45 cubic feet per minute.

The Standard of Purity of Air.—Pure mountain air in all parts of the world has been found to contain 3 to 4 parts of carbonic acid in 10,000. When people speak of good ventilation, they mean air which contains less than 0.07 per cent. of carbonic acid. Sanitarians declare that the limit should not exceed 0.06 per cent. In tunnels, 0.35 per cent. is allowed. Experience shows that an atmosphere containing 0.10 per cent. of this gas is not only offensive but unwholesome; 10 per cent. is deadly.

Pure carbonic acid, in small proportions, is not necessarily injurious. Men frequently work without ill effects in mineral-water factories, certain rooms in breweries and champagne-bottling vaults, where it may be present in the air to the proportion of 1.5 per cent. But in questions of ventilation great importance is given to the results of chemical tests of air in reference to this gas, because it is usually accompanied by vapors and suspended organic particles that are both offensive and dangerous. Variations in the amount of the gas to the extent of 3 or 4 parts in 10,000, indicate a corresponding variation in the extent of the vitiation. The quantity of carbonic acid can be determined with comparative ease by several methods, while there are no such tests for the impurities. For convenience the gas is measured, and thus is obtained a comparative measure of the extent to which the ventilation is being affected.

The following table shows the composition by volume of inspired and expired air:

	Pure air inspired.	Air expired.
	(A. Smith.)	(Huxley.)
Nitrogen	79.000	79.000
Oxygen	20.965	16.300
Carbonic acid	0.035	4.700
	100.000	100.000

It is seen that air which has been once breathed, contains a hundred times more carbonic acid than pure air; or, speaking roughly, it may be said to contain 5 per cent. while the oxygen is 5 per cent. less and the nitrogen remains unchanged.

From experiments conducted in a closed lead chamber, the following effects were observed by Prof. Angus Smith.

	Volume per cent. O	CO_2
Instantaneous headache occurred,	20.19	3.84
Decidedly close,	19.61	1.26
Candles went out,	18.80	2.28
Spirit-lamps went out in 150 minutes,	18.40	2.45
Difficult to remain in many moments,	17.20	

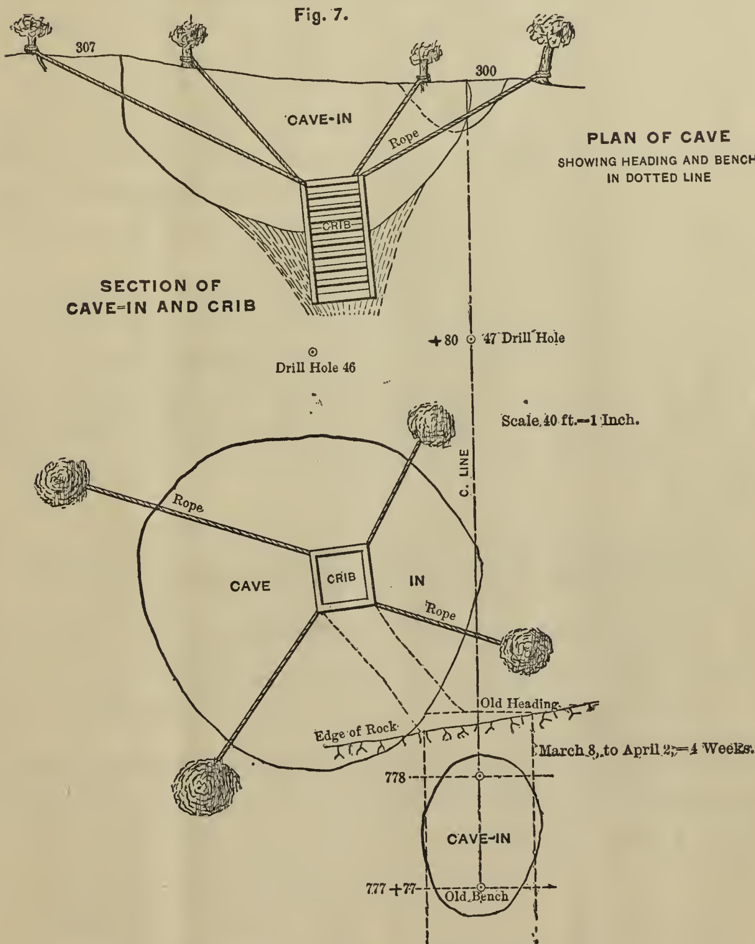
In a mine in England, the worst specimen of air examined gave:

	Volume per cent.
In one case minimum oxygen,	18.27
In another case maximum CO_2	2.50

The average of 339 analyses of air in mines in England gave:

	Volume per cent.
Oxygen, ...	20.260
CO_2	0.785
In the worst parts of theatres in London CO_2 . .	0.32
In workshops CO_2, ...	0.30
Smoking cars in United States CO_2, ...	0.98 to 0.369

Fig. 7.



Section and Plan of Cave. Shaft 13, South.

In Germany,* in a school-room of 252 cubic meters capacity and containing 64 children, a series of 14 experiments was made in one

* *American Chemist*, vol. i., p. 158.

day. The carbonic acid contained in the air of the room varied from 0.221 per cent. to 0.936 per cent.

A man inhales at least 22 cubic inches at each breath, which, at 20 respirations a minute, gives 15 cubic feet as the quantity passed through the lungs in an hour. The air exhaled contains from 4 to 5 per cent. of carbonic acid; so that 0.6 or 0.˜ of a cubic foot of this gas is given off in this time, supposing him to be awake and at rest. The amount of carbon eliminated in 24 hours is represented by a piece of charcoal weighing 8 oz. When at work, the respirations will be at least four times faster and the air required will be 60 cubic feet an hour, and the carbonic acid expelled 2.40 cubic feet.

As to the quantity of cutaneous excretions, few authorities give available figures, and those who do, differ widely. Huxley states that a man exhales from the lungs 12,000 grains of carbonic acid in 24 hours, and in the same time, he throws off from the skin 400 grains, also 300 grains of solid organic matter.

Dalton states that in 24 hours the quantity of carbonic acid amounts to 0.5 per cent. of that expelled from the lungs; and from figures given, it is deduced that the solid organic matter is 590 grains. The average per hour may be assumed to be: carbonic acid, 17 grains or 3.5 per cent. of that expelled by breathing; solid organic matter, 15 grains or 3.0 per cent. of that expelled by breathing.

	Per hour.	
Carbonic acid expelled from lungs while working, . .	2.40	cubic feet.
Carbonic acid expelled from skin while working, 3.5 per cent.	.08	"
Total carbonic acid expelled from lungs and skin while working, ...	2.48	
Solid organic matter expelled from lungs and skin while working, ...	60 grains.	

It is assumed that the proportion of carbonic acid in the air of the tunnel should not exceed 0.35 per cent. In order to keep it at this standard a man will require:

	700	cubic feet	of air	an hour.
Or,	11.6	"	"	per minute.
For 1 grain of organic matter. .	1.5	"	"	"
Total required, ...	13.1	"	"	"
For lamps, ...	7.1	"	"	"
Total, ...	20.2	"	"	"

Or, the air required for a man and lamp is, in round numbers, 20 cubic feet a minute.

A mule is supposed to require six times as much as a man, or 78.6 cubic feet. Since each mule carried a lamp, the total air required for a mule was 92 cubic feet.

The Gasoline Torch.—On the northern portion of the work, three or four of these torches were used in each heading and sometimes as many as six or eight by the bricklayers; on an average, one torch served for five men. On the southern portion of the aqueduct, they were not so extensively used.

The torch held about $3\frac{1}{2}$ gallons of gasoline or naphtha (25 lbs.) and was refilled every half-shift; so it consumed about 5 lbs. of gasoline per hour. In the combustion of gasoline the following reaction takes place:

$C_5H_{12} + 16\ O = 5\ CO_2 + 6\ H_2O.$

$72 \quad + 256 = 220 + 108.$ Then,

72 : 256 : : 1 lb. gasoline burned : 3.56 lbs. O required

72 : 220 : : 1 lb. gasoline burned : 3.05 lbs. CO_2 produced.

72 : 108 : : 1 lb. gasoline burned : 1.5 lbs. H_3O (aqueous vapor).

One cubic foot of air at 60° weighs 0.0763 lbs. The oxygen in it $= 0.0763 \times 23\% = 0.0176$ lbs. Hence the quantity of air required to furnish 1 lb. of oxygen $= \dfrac{1}{0.0176} = 57$ cubic feet.

One cubic foot of carbon dioxide at 60° = 0.1167 lbs.; therefore, 1 lb. carbon dioxide = 8.57 cubic feet. Hence for the combustion of 1 lb. of gasoline, there is required, 3.57 lbs. O $\times$ 57 = 203.5 cubic feet of air. As 5 lbs. are burned per hour, 17 cubic feet of air are required each minute. The carbonic acid produced would be: 3.05 pounds $CO_2 \times 8.57 = 26.1$ cubic feet, or, per minute, 2.20 cubic feet. To dilute this to the standard would require 630 cubic feet of air per minute, or sufficient for 32 men with lamps. One torch served for 5 men, therefore its effective light or work was one-sixth that furnished by the miners' lamps.

The gasoline torch may be most excellent for street-peddlers, but is a fiendish device for use in a tunnel.

The Smoke and Carbonic Acid Produced by a Miner's Lamp.—The attempt was made to estimate approximately the amount of smoke produced. As this depends upon the many variable conditions under which the lamps may be burned, the results of a rough average determination will answer the purpose as well as a more complete analysis. The lamp was weighed and placed in a large

china plate, and enclosed by a cylinder of stiff paper, 24 inches high, so arranged as to admit variable quantities of air. Another large plate was suspended from above. Of course, much of the smoke escaped, but that deposited on the paper and plate was collected and weighed. The test was made with the ordinary 150° kerosene oil used in the tunnel.

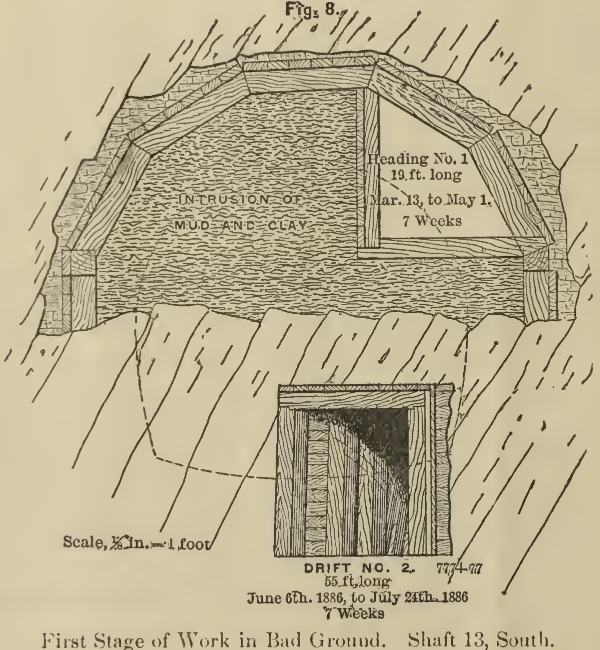
The average of six trials gave :

Soot collected per hour, ...	23.1 grains,	2.81 per cent.
Oil completely burned per hour, . .	800.1 "	97.19 "
Oil used per hour, ...	823.2	100.00 "

In other words, a miner's lamp used about 2 ounces of oil an hour, of which 3 per cent. went off as smoke.

The following is the reaction occurring when kerosene oil is com-

Fig. 8.



First Stage of Work in Bad Ground. Shaft 13, South.

pletely burned: $C_6H_{14} + 19O = 6CO_2 + 7H_2O$; $86 + 304 = 264 + 126$. Then, 86 : 304 : : 1 pound of oil burned : 3.53 oxygen required; 86 : 264 : : 1 pound of oil burned : 3.07 CO_2 produced; 86 : 126 : : 1 pound of oil burned : 1.46 H_2O produced. Hence the air required for the combustion of 1 pound of kerosene is 3.53×57

= 201.2 cubic feet; but the lamp uses per hour, 823 grains less 3 per cent. in smoke = 0.114 pound; the requirement of air per hour is therefore 201.2 + 0.114 = 23 cubic feet.

The carbonic acid produced per hour is 3.07 pounds × 8.57 × 0.114 = 3.00 cubic feet.

To dilute this to the standard will require 854 cubic feet of fresh air, or 14 cubic feet a minute. The smoke amounts to 23 grains an hour, or about 0.4 grain a minute. It is assumed that the deleterious effects of organic impurities are one-third greater than those of the inorganic. Then the air required to counteract the presence of each grain of solid inorganic matter should be 0.5 a cubic foot a minute. Therefore, the total air required for each lamp will be 14.2 cubic feet. A candle requires 12 cubic feet per minute.

When the electric lights were used, one lamp or candle served for two men.

Gas and Dust Formed by the Explosion of Dynamite.—Nitro-glycerine has a specific gravity of 1.6, and burns at 360°. On combustion it does not yield free oxygen, but a large quantity of protoxide of nitrogen. The following equation will give some idea of the mode of explosion:

$$2(C_3H_5N_3O_9) = 6CO_2 + 5H_2O + N_2O + 4N$$
$$454 \quad - \quad 264 + 90 + 44 + 56$$

Analysis after explosion:

	Per cent.
CO_2,	45.72
NO,	23.36
N,	33.92
	100.00

The volume of gas formed by explosion of one kilogramme = 0.71 cubic meters, which in English measure corresponds to 1 lb. and 11.37 cubic feet.*

Hence, per pound of nitro-glycerine exploded, there would be produced 0.4572 × 8.57 = 4 cubic feet CO_2.

The quantity of dynamite used during a shift was 32 lbs. of 60 per cent. in the heading and 38 lbs. of 40 per cent. on the bench, or in round numbers 7 lbs. of 50 per cent. per hour.

Therefore, the air required to dilute to the standard proportion the 2 cubic feet of carbonic acid formed from the explosion of 1 lb.

* Drinker *On Tunneling*, p. 67.

of 50 per cent. dynamite is 570 cubic feet per hour, or 9.5 cubic feet per minute.

The absorbent was composed of wood-pulp, 32.5 per cent.; sulphur, 5 per cent.; nitrate of soda, 62.5 per cent. This of itself forms a gunpowder, and produces about as much carbonic acid as the glycerine. The smoke and gases produced vary with the absorbents used. When infusorial earth was used, it formed about 80 per cent. of the mass, and upon explosion was diffused as an impalpable powder. The dust formed from this source was 0.4 lb., or 2800 grains, or 50 grains a minute.

According to the absorbent used, we have then the following air-requirements per minute:

	Infusorial earth.		Wood-pulp, etc.
For CO_2, ...	9.50		9.50
For 50 grains of absorbent dust, . .	25.00		9.50
Total cubic feet of air per minute, .	34.50	or	19.00

The local conditions affecting an explosion we will not discuss. But an allowance must be made for the dust derived from the rock after an explosion. This will vary with the character of the rock, and whether it is wet or dry. It cannot be even approximated. So for ordinary rock it would seem proper to multiply the above figures by 3 or 5, and, in cases where the material is very dry, to multiply by 6 or 10. Assuming the gases to be uniformly distributed during ten hours for each pound of 50 per cent. dynamite burned per shift, there should be allowed of fresh air 100 cubic feet per minute, and when the rock is very dry, 200 cubic feet per minute.

Dust Formed during Drilling.—Usually, in driving a heading, there are at least four holes driven, inclining upward, so that water cannot be poured in. From these dry holes the dust is derived. The holes are 8 feet x $1\frac{3}{4}$ inches diameter, the contents 231 cubic inches, or 0.13 cubic feet = 22 lbs. Assuming that one-quarter of this amount is pounded to an impalpable powder, then during the seven hours that the drilling lasts 100 grains of dust are derived from each hole per minute. Allowing 0.5 cubic foot of air for each grain of dust, the air required per minute will be 50 cubic feet.

The probable quantity of dust a man inhales during a shift, working in an ordinary heading, may be stated as follows:

There is produced—

20 miners' lamps, soot, ...	8	grains per minute.
7 lbs of dynamite, ...	350	"
4 dry-holes, ...	400	"
Total per minute, ...	758	

The working-space may be calculated as follows:

Heading area, ...	105 sq. ft. × 50 =	2550 cubic feet.	
Enlarged section, , . .	283 " × 50 =	14,150 "	

or, in round numbers, 16,000 cubic feet. Hence each cubic foot of air-space contained about .05 or $\frac{1}{20}$th grain of dust.

Supposing a man at each breath to receive only half of a full dose, after ten hours he would have inhaled into his lungs 15 grains of solid matter. Physiologists do not state how much a man can stand, but say that "the suspended particles are drawn into the air-passages at each inhalation, and there find lodgment upon the delicate mucous surface with which they come in contact. The irritation there set up disturbs the working of the lungs, and, if maintained, eventually ends in organic disease."

Mr. C. L. Kalmbach made the following experiments in the tunnel:

Into a beer-bottle, the bottom of which was broken off, he placed a piece of sponge moistened with glycerine, about the size of a man's fist. Into the neck of the bottle he inserted the nozzle of an ordinary house bellows, each stroke of which delivered about a quarter of a cubic foot of air. After 26 strokes of the bellows, or $6\frac{1}{2}$ cubic feet of air, had been delivered, the sponge was completely blackened and impregnated with smoke and dust.

From the foregoing computation we have the quantity of fresh air necessary per minute to dilute the carbonic acid to the required standard.

Assuming a heading and bench to be worked together, and neglecting the explosions, we have the following air-requirements per minute:*

	In Heading. Cub. ft.	On Bench. Cub. ft.	Total.
17 men at 20 cubic feet of air, . . .	340	18 men, 360	700
1 mule at 92 cubic feet of air, . . .	92	92	92
	432	452	792
Deduct 3 drills at 45 cubic feet of air, .	135	1 drill, 45	180
Total, ...	297	407	612

It would be very convenient to assume that the gases produced by the explosions are distributed throughout the shift, and determine

* For fuller information on this subject the reader is referred to Andre on "Coal Mining," and A. Smith on "Air and Rain."

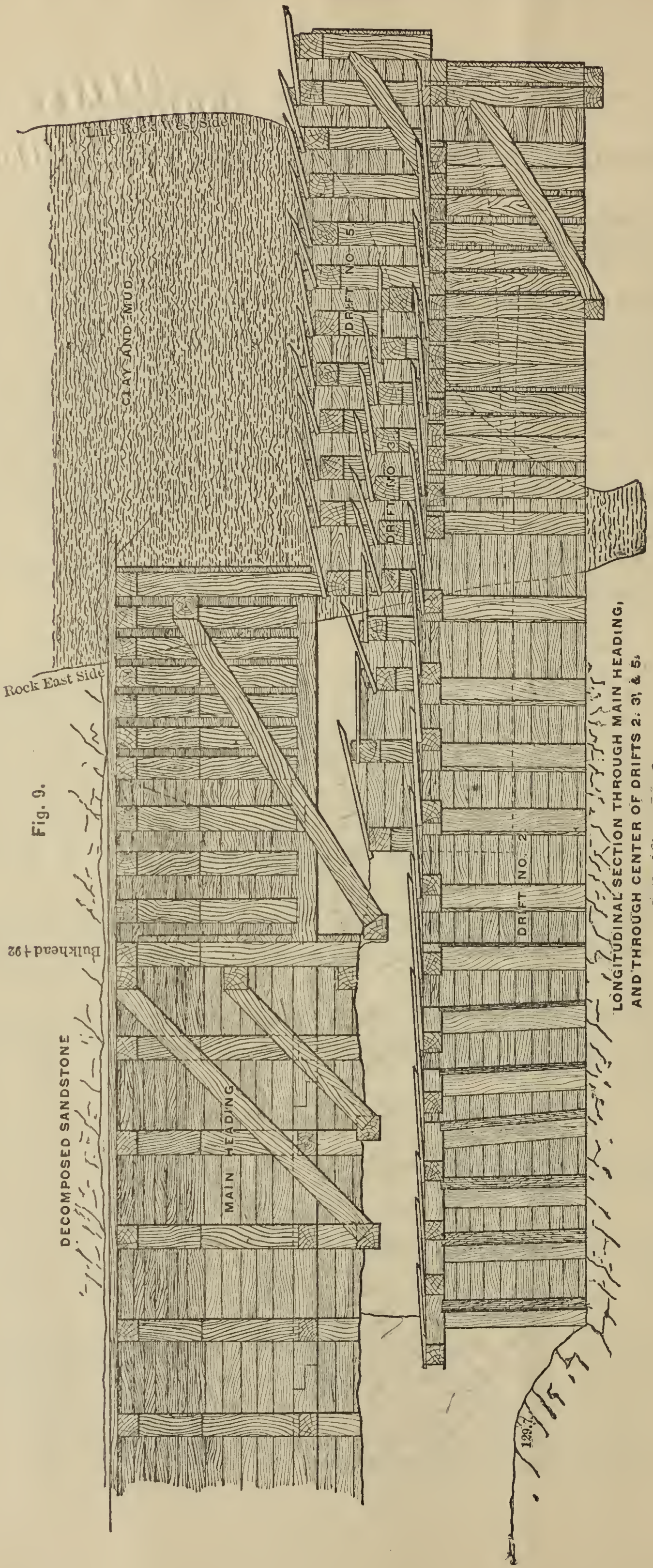


Fig. 9.

Drifts and Timbering in Bad Ground. Shaft 13, South.

the air required, but unfortunately the smoke and dust formed are too variable to permit any estimates of practical value.

The blasting was generally done at the end of each shift, so that an hour intervened before the work was resumed. During this time the smoke filled the entire tunnel. Occasionally the compressed air-valve was opened, and the heading thus cleared for a short time. The duration of the smoke in the tunnel depended on the atmospheric conditions. It often happened that on a rainy day, or after a rain, the tunnel was comparatively free, while on clear warm days it was so smoky that a lamp could scarcely be distinguished at a distance of 50 feet. Doubtless the moisture of the air was precipitated as fog, and much of the trouble attributed to the smoke was due to this cause.

Ordinarily, a tunnel 3000 feet long by 300 feet in section would by natural ventilation become practically clear, that is, so that a light could be plainly distinguished at a distance of 150 feet, about ten hours after a blast. The smoke may, therefore, be said to move at the rate of 5 feet a minute.

In artificial ventilation of mines the air-current is necessarily continuous, and the allowed velocity is from 2 to 6 feet per second; but as active ventilation of a tunnel is only required immediately after a blast, it would obviously be unnecessary to establish a plant of such power. It is believed that a fan capable of removing half of the smoke, and, consequently, the dust, of the tunnel two hours after a blast, is all that is necessary. Under these conditions, with a tunnel of the above dimensions, the volume of air required to be removed per minute is 3800 feet, and, as the natural ventilation is 1500 per minute, then the capacity of the fan should be 2300 feet per minute.

The blowers employed, when working at 145 revolutions per per minute, and with all the connections in good order, were capable of doing the above work, or sufficient for one heading. But, as only one blower was usually provided for each shaft, the ventilating capacity was just half what was required. According to the Miners' Act of Pennsylvania and the order of the Board of Health of the State of New York, 60 cubic feet of fresh air are required for each man. For miners this is barely sufficient; for a tunnel after the smoke is removed it is one-half too much.

Analysis of the Air of the Tunnel.

The first apparatus used was Owen's carbonator. The principle

of this apparatus is to use a variable quantity of air with a standard solution of hydrate of barium in connection with an indicator. The apparatus is fully described in the *Sanitary Engineer*, vol. ix., p. 479. On account of the poor and variable lights it was difficult to determine the change of color in the tunnel; each experiment consumed more than an hour, and the apparatus was too complicated to handle, so after a time it was given up.

Pettenkofer's process was then used. The principle is that a known volume of air is made to act upon a definite quantity of standard baryta-water (standardized by oxalic acid solution) in such a manner that the carbonic acid is completely fixed by the baryta. The baryta-water is then poured out into a cylinder and allowed to deposit with exclusion of air; a part of the clear fluid is then removed, and the baryta remaining in solution is determined. The difference between the oxalic acid required for a certain quantity of baryta-water before and after the action of the air gives a basis for the calculation of the amount of carbonic acid present.*

The apparatus consisted of a Mohr's burette with float, a measuring-glass, some small flasks, and a gas-jar with a tight cover. An anatomical jar was used, the convexity of the cover was filled with cement, and to protect it from breakage and give facility of transportation, it was packed in an open wooden box with rope handles.

The analysis was conducted as follows: the jar filled with clean water was taken to the place in the tunnel where the air was to be examined, the water was emptied, the jar wiped out, 45 cubic centimeters of previously standardized baryta water poured in, and the cap secured. The operation occupied but a few minutes. The jar was then brought to the office and the solution tested.

Referring to the above analyses taken in the heading of Shaft 15, which may be considered as representing a fair average of the southern portion of the work, it is seen that often, when the ventilation was apparently very bad, the amount of carbonic acid was very low, and *vice versa*.

With the admission of 450 feet of air per minute, or nearly twice the quantity required for the number of men present, the proportion of carbonic acid was diluted to 0.141 per cent, which is about two-and-one-half times better than the assumed standard.

At Shaft 16, with partial ventilation, the carbonic acid present was 0.394 per cent., or greater than the worst recorded condition of

* For details see Fresenius' *Quantitative Analyses.*

Table II.

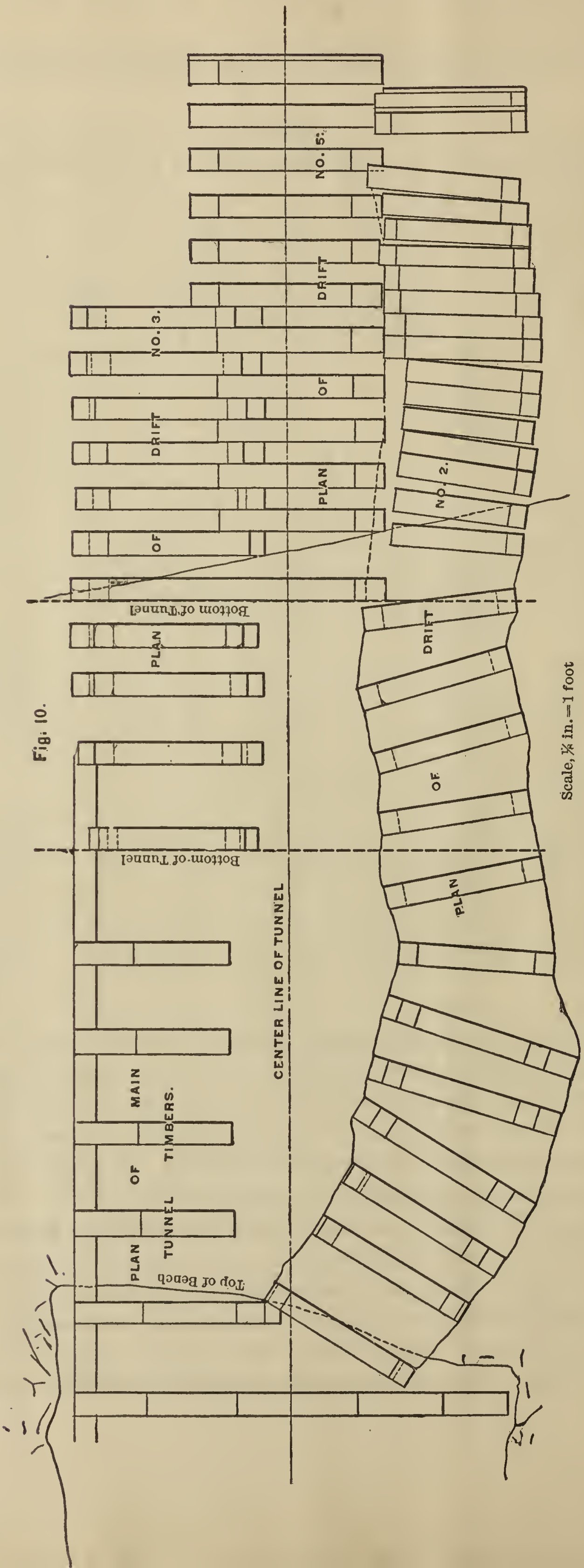
Analyses of Air of the Tunnel Taken in the Headings.

No. of observation.	Date.	Weather.	Outside.	Shaft.	Dist. from Shaft.	Dist. from Heading.	Number Lamps.	Number Candles.	Number Men.	Number Drills.	Thermometer.	Blower. Revolut'ns.	Blower. Cubic feet.	Hours after blast.	Per cent. CO_2.	Condition of ventilation.	Remarks.
1	Dec. 18, '86.			15N	2102							115	1222				Damper south closed.
2	"			S	2156							115	498				Both open.
3	" 20, "			N	2102							110	401				" "
4	"			S	2156							110	496				" "
5	" 21, "			N	2102							115	743				South closed.
6	" 22, "			S	2173							115	897				North "
			Mean..........		2350							113	471				The blower 158 ft. above tunnel.
7	Feb. 25, '87.	30	Clear.	N	2618	60	11		12	3	55	100	440	2	.138	Very good.	Carbonator used.
8	Mch. 1, "	30	"	N	2648	20	3		4	3	62	90		8	.165	" "	" "
9	" 7, "	32	"	S	2994	80	4	11	16	3	60	150	584	36	.113	" bad.	" "
10	" 12, "	38	"	N	2690	45	4		8	3	59	100	387	6	.142	Fair.	" "
11	" 14, "	41	"	S	3111	90	10	4	16	3	58	100	535	30		Good.	" "
12	" 21, "			S	2955							100	262				" broken during big run.
13	" 31, "	40	"	S	3249	78	13		19	3	60	120	172	10	.126	Good.	Blow-pipe broken.
14	Apr. 12, "	40	"	S	3331	80	5	10	20	3	60	100	148	6	.121	Very bad.	Carbonator used, blow-pipe broken.
15	June 17, "	91	Fair.	N	2927	45					60	120		7	.124	Bad.	Pettenkofer used.
16	" 30, "	90	"	N	3000	44	6	3	14	3	60	100		8	.182	Very bad.	" "
17	July 18, "	90	"	N	3017	150					60	150		4	.159	Bad.	" "
			Average.........		2832	69	7	7	12	3	59	114	446	8	.141		
18	July 7, '87.	90	Sultry.	16N	3775	50	3	8	17	2	62	0		3	.394	Very bad.	Blower occasionally running.
19	" 19, "	90	Clear.	"	3925	50	12	6	30	2	65	150		3	.471	" "	Blower occas'ly running dur'g big run.
20	" 22, "	90	"	"	3845	50	12	5	30	2	63	175		2	.577	" "	"
21	July 20, "	90	Clear.	3S	2830	70	18	Torches 5	37	3	62	0		6	.579	Very bad.	Shaft 350 feet deep, smoke boxes used.

a smoking car. At this shaft, when the blower was not running, and on the northern portion of the work, where natural ventilation was practically depended upon, the carbonic acid was 0.578, much worse than any smoking car, but nearly a quarter less than the average composition of the air of mines in England. It is to be regretted that there was no opportunity to make more tests.

General Conclusions.—From the foregoing it is seen that the vitiation of the air due to the respiration of the men and the combustion of the lights could be reasonably estimated and provided for. The same applies to the gases from the dynamite, but these were accompanied by the smoke, which varied according to the quantity of wood-pulp or other carbonaceous matter used with the absorbent, and even

Fig. 10.



Scale, ⅛ in.=1 foot

Plan of Fig. 9.

according to the loading and firing of the charge. The dust, of course, was a variable quantity, depending on the character of the rock.

It is believed that a ventilating-power sufficient to remove half the volume of air contained in the tunnel within two hours after an explosion would have satisfied practical conditions. After the smoke was removed, 30 cubic feet per minute for each man employed was sufficient. Chemically considered, the air in the tunnel, though it could easily have been kept purer, was no worse than in some public schools, and was not so poisonous as some persons asserted. The real trouble was from the smoke and dust. When artificial ventilation was used, the shafts, with the exception of No. 16, were provided with only one blower each, or half the necessary means; and of this, through carelessness and indifference, only about 50 per cent. of the useful effect was utilized. The additional expenditure at each of these shafts of the comparatively insignificant sum of $1500, and the exercise of a little care and humanity, would have insured decent ventilation.

An Example of Slow Work—The Excavation of the Tunnel through the Soft Ground of Shaft 13 (South), Station 773 + 52.

First or Development Stage.

On 1st June, 1885, the tunnel at the foot of the shaft was commenced, and advanced at the rate of 80 feet a month for 392 feet, through hard dolomitic limestone, which then became softer. Fifteen feet further, at station 777 + 59, on the east side of the heading, a fissure was cut on December 9th, and the trouble began. There poured out a mixture of decomposed limestone, clay, sand and dirty water, which soon partially filled the tunnel for 125 feet, and amounted to about 100 cubic yards. After three days the water became clear, the fissure was plugged with straw, and the heading advanced 20 feet further. Then, on December 22d, without warning, another outpour three times greater than the first occurred. The men were driven out, and everything in the heading for 50 feet was covered out of sight.

Timbering of the form shown in Fig. 8, page 22, so as to allow for 20-inch brick-work, was then commenced at the soft rock. At the end of two months the heading had been cautiously advanced 34 feet, to 778 + 13, and seventeen sets of timber placed, the last

two being re-enforced with heavy hemlock spreaders. A bulk-head was then built at the end of the timbers, at 778 + 09, this being the edge of the soft ground on the east side. The bench during this time had been brought up, and was 32 feet behind, at 777 + 77.

Second or Experimental Stage.

For several days the clay and mud in the face of the heading were continually forced inwards. Some idea of the pressure may be formed from the fact that the 24-inch oak logs used as rakers at the bulk-head became so crushed after twenty-four hours that they had to be continuously renewed. A small cave on the surface then occurred; finally, on February 20th, this was followed by a much larger one, about 25 feet east of the center-line. It was directly in line of a small stream (as shown on the map, Figs. 1 and 2, page 5), which partly filled it with water. The stream was immediately diverted, and a pump rigged to remove the water from the hole. This cave was supposed to be the mouth of the original fissure, and an abortive attempt was made to clog it up by throwing in bales of hay, cedar-brush, logs and stumps. Either from the fact that the course of the brook had not been properly diverted, or by reason of a sudden thaw, or local conditions, this débris gently glided down into the tunnel, completely filling it for 70 feet, and gradually sloping down to a depth of 1.5 feet for 312 feet, or to within 75 feet of the foot of the shaft. It amounted to about 1189 cubic yards.

The Crib.—Faith in the theory of a fissure in the limestone led to the plan of a crib (Fig. 7, page 19). It was aimed to strike the fissure, which was to be arched over, or otherwise closed. The dimensions were 12 x 12 feet on the outside. It was built in the hole, and consisted of wall-plates of 12 inch timber jointed at the ends, and held apart by vertical posts, 2 feet 10 inches long, placed at the corners, the whole system being held together by planks spiked on the outside. It was sunk to a depth of 50 feet, when, hard-pan occurring on the west side, it began to sink irregularly. Sheet-piling was then driven on the east side, and finally, to keep the crib from toppling over, ropes were attached to the top and bottom sets, and secured to trees and posts on the surface.

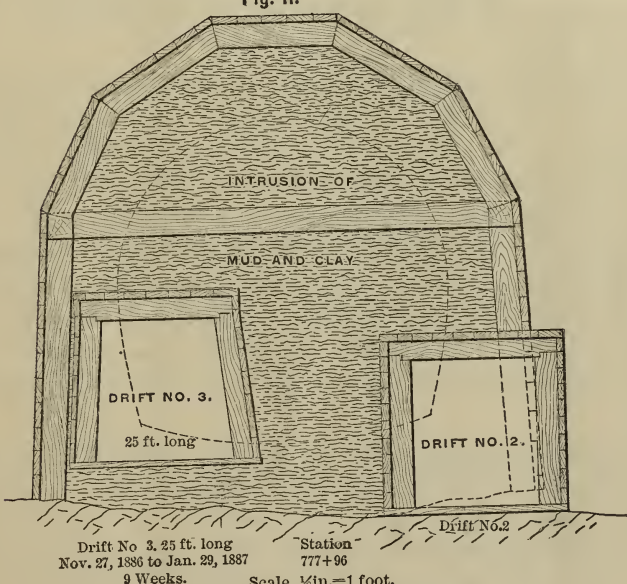
After three weeks' work and the expenditure of about $900 the contractors concluded that they had expended the amount allowed "for any work they should do on the surface, to be paid after the the tunnel was through," and stopped.

At this time the diamond-drill was brought up, and hole No. 46,

station 778 + 87.33 east of center-line, was sunk 191 feet, 79 feet through gravel and boulders, and 112 feet in one day through clay and mud. By reason of these developments the work was ordered to be stopped. After two years, the hole was filled up with 2533 cubic yards of earth, the contract-price of $5000 had to be paid, and, to the relief of all concerned, the crib was buried out of sight.

At this time several plans were proposed. Among the most feasible were the following: Mr. Charles M. Kalmbach, a well-known tunnel-expert, proposed to drive a heading below sub-grade and fill with concrete; to then gradually widen out, and thus obtain a foundation. The division engineer in charge, Mr. Alfred Craven, proposed instead, a timber platform of oak or Georgia pine, upon which

Fig. 11.



Section Showing Drift No. 3.

the concrete should be laid, and to change the section from the horseshoe to the circle. This was generally conceded to be right, but in the following August it was decided to use white oak for the platform, and return to the horseshoe-section; and this plan was formally approved January 10, 1887, but not fully adopted by the contractors until the year after. The functions of the engineers were confined to giving lines and grades, and suggesting plans to the contractors, who executed the details of the work in their own way, and assumed the responsibility of any miscarriage.

For the next year the work was carried on with a series of experimental drifts, conforming to no regular system of timbering, and the means adopted were entirely inadequate to the work in hand.

The First Drift.—This was started at 777 + 77, and in two weeks progressed 18 feet. It was driven within the original heading, on the west side. It advanced 20 feet, when the sand rushed in through a 12-inch opening, and filled it up for 12 feet. A bulkhead was then built across the entire heading, and the mud removed, which occupied three weeks longer. (Figs. 9 and 10, pages 26 and 30.)

About May 1st, Mr. Charles Sooysmith visited the tunnel with a view to trying the freezing-process, and it is reported that he offered to contract to drive the tunnel for $1000 a foot.

The next experiment was to drive eight 2-inch pipes with perforated ends 30 feet into the sand and mud, in order to drain it. This was not a success.

The Second Drift.—Forty feet north a sump was sunk 8 feet deep on the east side, and a ditch carried $4\frac{1}{2}$ feet below invert-grade, to the bench at + 77. Here a bottom drift was started, on the west side. It was 5 feet in the clear, and was timbered with square sets placed 2 to 3 feet apart; nineteen regular sets and ten intermediate sets were put in. It was 54 feet long, 35 feet through decomposed rock, the remaining 19 feet through heavy ground which caused the timbers to crack. Finally, mud ran in as fast as it could be excavated, so that the drift was abandoned after eleven weeks' work. Figs. 8, 9 and 10, pages 22, 26 and 30, show it in section, elevation and plan.

The great trouble was to drain this ground. The water amounted to 160 gallons per minute. After ten months it had not sensibly diminished, and, in fact, it never did diminish. At first sight, one might suggest driving a drift to the Saw Mill river, but unfortunately the bed of the river was higher than the grade of the tunnel.

There was some talk of diverting the line of the tunnel to the valley on the west, and making an open cut; and with this view a topographical survey was made of the ground between Shafts 13 and 14. This was found to be impracticable.

The work was then abandoned for ten weeks. Then the excavation was resumed and the masonry commenced. After seven weeks the tunnel was sufficiently widened, and on 4th December the arch reached 777 + 95, just 18 feet short of where the heading had been nearly a year before.

During the next four months, or until April 2d, 1887, the following drifts were run: Figs. 9, 10, 11 and 12.

Drift No. 3.—East side at grade, nine weeks, 27 feet to + 22.

Drift No. 4.—Top-center, one week, 8 feet to + 13.

Drift No. 5.—Center at grade, 6 weeks, 24 feet to + 32.

These drifts were no more successful than the others; however, they were widened out, the arch was carried to 778 + 05, and the invert and side-walls to + 08, or the edge of the soft ground. The extent to which it had been honeycombed by successive drifts, is shown in Fig. 12.

Third or Systematic Stage.

In March, there occurred an entire change in the management, and on April 2d, M. Nolan was appointed foreman in charge. The English system was introduced, and the work, without serious interruption, was completed in a year and two months.

The entire excavation made was allowed within the limit of 676 square feet, or 26 x 26 feet. This permitted the placing of a 2-foot timber platform and 24 inches of brick masonry. The average area excavated was 507.7 square feet.

The first two stretches of 13 and 12 feet occupied respectively twenty and twelve weeks. Against advice, a top-central drift was first run about 18 feet, and, as the rock was found on the west side, the widening was done from west to east; about 15 crown-bars were placed, and a bulkhead built. The bench was then removed, to 4.2 feet below grade. A platform 2 feet thick, formed of cross and longitudinal timbers 12 x 12 inches, was built. Upon this the invert was laid, and the masonry completed.

In widening out the second stretch, several of the crown-bars on the east side broke, and the weight of the ends resting on the masonry arch at + 18 caused it to crack for 8 feet. This crack extended irregularly down the east haunch and side-wall. Fig. 18, page 50, shows the extent of this defect. This difficulty was overcome by supporting the arch with oak centering, and also by placing a large 24-inch longitudinal timber in the center, supported by posts about 6 feet long from the invert and mud-sills. From this, radial pieces were placed to the crown-bars above. Finally, the bottom was removed and platform placed. The cracked portion of the arch was subsequently rebuilt.

Top-drifts were still persisted in, both here and in the heading from Shaft 13 A, which had now reached the other end of the soft ground; but after two weeks' further trial the foreman was finally forced by the mud, sand and water to abandon them.

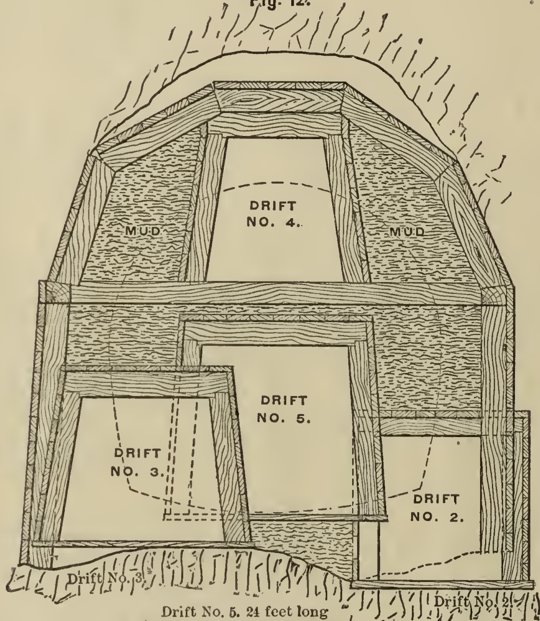
The English system was finally adopted, and the following is a description of its application:

The beginning was made 4 feet north of the soft ground.

The first 54 feet (778 + 05 to 778 + 45, 40 feet, and 779 + 19 to 779 + 05, 14 feet), as before-mentioned, were worked from the top, down; the remaining 60 feet from the bottom up.

Referring to Shaft 13: on January 28th, 1888, the excavation and masonry had reached 778 + 45, and a small preliminary bottom drift, 2 feet by 3 feet, was driven through, connecting both headings,

Fig. 12.



Drift No. 5. 24 feet long
Feb'y 5, 1887, to March 12, 1887,
5 Weeks
Station 778 08
Scale, ⅛ in. = 1 foot.

Successive Drifts in Bad Ground, Shaft 13, South.

and the top drift from the driving of the previous section, was at Station 778 + 55.

The First Operation.—The lower drift was enlarged to 6 feet by 8 feet for a distance of 25 feet. (A, Fig. 13.)

The Second Operation.—Widening out of the drift. Bearing-bars, B (Fig. 13, page 38), 20 feet long, were placed under the caps, and supported by posts, resting on longitudinal sills *bb*. The operation of widening out, on either side as most convenient, was then done,

and the bars, posts and sills ($c, c, c,$ d, d, d and e, e, e) placed. The process of widening is shown on the left of the drawing, Fig. 1.

The Third Operation.—The placing of the timber platform. The previous operation being well advanced or completed, sheet-piling was driven down, 5 or 6 feet outside of the sills b, b, e, e, etc., and the enclosed spaces were excavated in pockets to a depth of 4.5 feet below invert-grade, for a length of 18 feet, and as wide as possible, generally 10 or 15 feet. Posts b', e', etc., placed at intervals measuring 7 feet, Figs. 1 and 2, resting on foot-boards in the mud, now support the system. Sheet-piling (F, Fig. 14), 3 or 4 feet long, was then driven across the bottom of the excavation about 15 feet in advance of the completed invert. This prevented the mud from being pumped out from beneath the platform during the construction of the succeeding section. The longitudinal sills G, in variable lengths up to 15 feet, were then placed in the excavated spaces between the posts b' b' b' e', etc. Underpinning was then employed in order to get the longitudinal sill in the space interrupted by the line of posts. Immediately behind the first post, a cross-sill (H, Fig. 13) 6 feet long was placed on blocks 6 inches above the sills in place. The weight was transferred to this and the first post removed. The second post was removed in a similar way. The third post was supported by struts (X, Figs. 13 and 14). The sill G in the vacant space was in half-lengths and was slipped into place as shown in Fig. 14. The cross-sills H were then placed. The sills put in were as long as circumstances would allow, and arranged to break joints. The posts e' (Fig. 16), being on the outside, could seldom be removed; and longitudinal pieces were placed between them. The excavated space ahead of the platform was used as a sump for pumping.

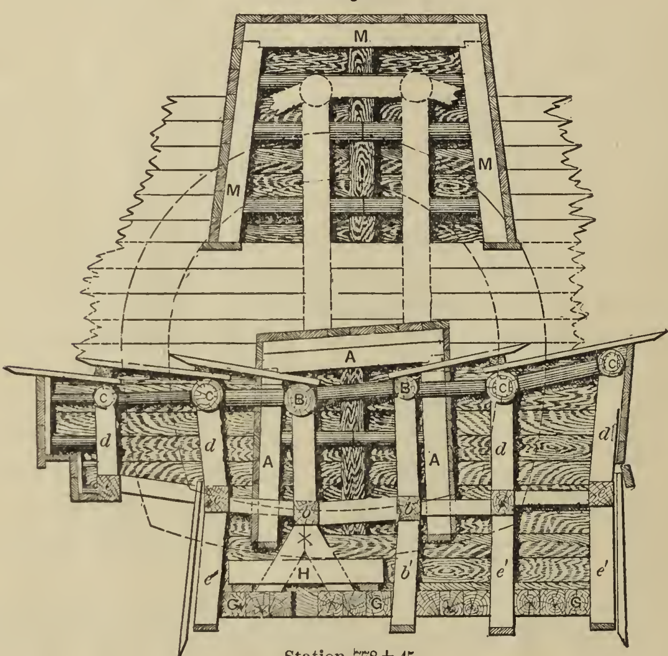
The Fourth Operation.—The platform being completed, the cross-beams J (Fig. 15), supported by the inclined posts k, k, were placed about 3 feet between centers under the bearing-bars B and C, and well wedged up. The posts and sills, $b, b,$ $c, c,$ and d were removed, and the central portion of the invert built between K K, which were replaced by L L (Fig. 15), and the remainder of the invert and 2 feet of side-wall and backing was built (Fig. 16, page 48).

While the masonry was being built, the top-heading, M (Fig. 15), was advanced 15 feet to + 70.

The Fifth Operation.—The crown-bars R_1 R_2, etc. (Figs. 15 and 16), were placed. The back ends rested on the arch already built, and the heading-ends of the first two were supported by the

posts P (Fig. 17), resting on the cross-sill O, and two longitudinal sills N, placed in the top-heading (Figs. 15, 16 and 17). The excavation was carried down and out at the same time, and the other bars were supported by the struts Q resting on the bearing-bars, B, C, etc. (Fig. 15). The large beam S (Figs. 16 and 17), 24 inches by 24 inches, 26 feet long, was then placed ahead of the invert, and supported by posts resting on sills in the bottom, and strutted back to the invert by the rakers u. Posts T were placed under the crown-bars to this sill, and it also served as a bearing for the bulkhead against the

Fig. 13.



Advance of Drift by English Method.

mud in the face. When the section was completed, it was cut off and removed, the ends being built in. To support and strengthen the crown-bars, the segmental timbers v, supported by posts resting on foot-blocks on the masonry already built, were put in, one or two feet apart as necessary. The sidewalls and the arch were finally constructed. No attempt was made to withdraw the crown-bars.

This was the general order of operations, which were varied in their successive stages according to circumstances.

Table III.

Showing in Detail the Time Occupied by the Different Operations, as Above Described.

Date.	Weeks.	Work Below Spring-Line,	Work Above Spring-Line.	Masonry.
1888.				
Jan. 28...	....	Drift 2 ft. x 3 ft., 778+75	Heading ....778+55	.... 778+45
Feb. 4...	1	Drift widened, 6 ft. x 8 ft., 778+70	....	....
" 18...	2	Platform built, 778+60	....	....
" 25...	1	....	Drift..................778+62	Invert completed...778+60
Mar. 3...	....	....	" ....778+70	....
" 3...	1	....	" widened ...778+50	....
" 17...	2	....	" " &com.778+60	....
" 24...	1	....	....	Sidewalls and arch 778+60
	8			
" 31...	1	Widening drift...........	Drift.................778+75	....
Apl. 14...	2	Platf'm finish'd, +75	Widening out..............	Centre of invert built.......
" 21...	1	....	" "	Inv't & 2 ft. S. wall.778+75
" 28...	1	....	Cr'n bars placed, " +78	....
May 5...	1	....	....	Arch & S. wall comp...+75
	6			

There is no published record of a tunnel-foundation having been built as described above.

At first some difficulty was caused by carelessly removing the sheeting in front of the invert and allowing some of the material beneath to be pumped out, thus undermining it. Some of the crown-bars on the east side were broken, and some placed too low. They were cut out and replaced by segmental arches of oak, and finally these arches were always used to relieve the weight of the crown-bars on the brick arch; and as a precautionary measure, the last five stretches, one of them in 13 A, were built in this manner. The heading being opened through to 13 A for four months, obviously drained and facilitated the latter portion of the work.

The last stretch was finished at 6 P.M., Friday, June 1, 1888.

According to a most liberal estimate, including the cost of sinking of Shaft 13 A, the cost for 110 feet was at the rate of $416.00 per foot. The amount paid for this work was at the rate of $539.00 per foot.

Fig. 19 shows, in general longitudinal sections, the progress of the work; and Fig. 20 is a graphic record.

Table IV.

Progress through Soft Ground, Shaft 13. (*Sta.* 773 + 52.)

Date.	Weeks Worked. No Progress.	Weeks Worked. Progress.	Weeks Worked. Total.	Headings. Sta.	Lineal Feet. Progress.	Lineal Feet. Dist. f'm Shaft.	Bench. Sta.	Bench. Progress.	Remarks.
First, or Development Stage.									
	......	......	......	777+44	2	392	....	......	Soft limestone begins.
Dec. 9, '85	......	......	......	+59	15	407	....	......	Fissure 2 feet wide on east side.
" 12, '85	......	......	......	+66	7	414	776+91	......	
" 19, '85	......	1	1	+79	13	427	777+37	......	Outpour of mud and water. Men driven out.
Feb. 13, '86	4	4	8	778+13	34	461	777+77	......	Timbered from 777+44 to end of heading.
Totals.....	4	5	9						
Second, or Experimental Stage.									
Feb. 13, '86									
Apl. 17, '86	9	......	9	777+77	0	......	....	......	Building crib and removing mud.
May 1, '86	......	2	2	777+95	18	......	....	......	Drift No. 1. Top drift west side. McLear, Supt.
" 29, '86	3	......	3	....	......	......	....	......	Driven out, and bulkhead built at + 92. Cleaning out mud and trying driven wells.
Aug. 7, '86	......	11	11	778+31	54	......	Arch.	......	Drift No. 2. Lower west drift. Abandoned.
Oct. 16, '86	10	......	10	....	0	......	777+45	0	No work of excavation. Masonry commenced.
Dec. 4, '86	......	7	7	....	......	443	+95	50	Bulkhead removed and arch extended.
				777+95	......				
Jan. 29, '87	......	7	7	778+22	27	......	778+05	10	Drift No. 3. East side at grade. Abandoned.
" 22, '87	......	......	......	778+05	......	453	....	......	Drift No. 4. Top central.
" 29, '87	......	......	......	778+13	8	461	....	......	Abandoned.
Feb. 1, 87	......	......	......	....	......	......	....	......	Maddox took charge.
" 12, ,87	2	......	2	....	......	......	....	......	Cleaning out.
Mar. 19, '87	6	......	6	....	24	......	....	......	Drift No. 5 too high, and no benefit. Abandoned.
Apr. 2, '87	2	......	2	....	......	......	....	......	
Totals,	32	27	59						
Third, or Systematic Stage.									
							Masonry and excavation Progressed simultaneously.		Foreman Nolan took charge.
Apr. 2, '87	......	......	......	778+05	......	453		......	Invert was 3 feet in advance.
Aug. 20, '87	......	......	20	+18	13	466		......	Top heading driven first.
Oct. 12, '87	......	......	12	+30	12	478		......	" " " "
									Bottom heading driven first.
Jan. 28, '88	......	......	11	+45	15	493		......	Small drift (2 ft. x 3 ft.) connects shafts.
Mar. 24, '88	......	......	8	+60	15	508		......	Bottom heading driven first.
May 5, '88	......	......	5	+75	15	523		......	" " " "
June 1, '88	......	......	4	+90	15	538		......	" " " "
Totals.....	......	......	60		85				Average progress per week, 1.4 ft.
Dec. 4, '86	......	......	......	....	......	......		......	Commenced to sink shaft 13A. (Sta. 779 + 96).
" 17, '87	......	....	......	779+19	......	77		......	
Feb. 25, '88	.....	10	10	+05	14	91		......	Top heading driven.
Mar. 24, '88	......	4	4	778+90	15	106		......	Bottom heading driven.
Totals.....	......	......	14		114				Average progress per week, 2.07 ft.

From the foregoing table we see that the first or development stage, December 9th, 1885, to February 13th, 1886, occupied 9 weeks; the second or experimental stage, February 13th, 1886, to April 2d, 1887, 59 weeks; the third or systematic stage, April 2d, 1887, to June 1st, 1888, 60 weeks, for 14 weeks of which the work was being done at both ends.

Notes on the Time and Cost of Drilling through Different Materials with the Diamond Drill.

This work was done for the purpose of exploration on the line, between Shafts 13 and 14. The materials passed through were clay, gravel, boulders, decomposed and hard gneiss and limestone.

There were fourteen different holes bored, the aggregate depth of which was 2084 feet. A daily record was made of the material passed through, as shown by the following table:

TABLE V.

No. of hole.	Date.	Foremen.	Men.	Clay & Gravel.		Boulders.		Soft Rock.		Hard Rock.		Days Moving.	Days Accidents.	Total feet.	Total days.
				Feet.	Days.	Feet.	Days.	Feet.	Days.	Feet.	Days.				
46	March 23–27........	1	4	29	1	21	2	141	2	......	......	......	......	191	5
47	" 29 to April 5.....	1	4	18	1	26	2	151	4	......	......	......	......	195	7
48	April 6–23....................	1	4	29	1	21	2	23	2	101	7	1	3	174	16
49	" 26 to May 3..........	1	4	33	1	48	2	79	3	......	......	1	1	160	8
50	May 6–15......................	1	4	14	1	18	1	28	1	77	6	2	1	137	12
51	" 19 to June 5.........	1	4	44	1	33	3	22	1	36	3	2	5	135	15
52	June 6–30.....................	1	4	24	1	65	6	......	......	10	1	1	13	99	22*
53	July 1–23......................	1	4	22	1	77	12	55	6	......	......	......	......	154	19*
54	July 27 to Aug. 11........	1	4	24	1	59	11	73	1	......	......	2	......	156	15
	Aug. 12–19 (7 days)......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
55	Aug. 20 to Sept. 10......	1	5	19	1	71	8	47	1	6	1	......	8	143	19
56	Sept. 13–21...................	1	5	34	1	40	3	98	4	......	......	1	......	172	9
54	" 22 to Oct. 9.........	1	5	......	......	......	......	13	1	1	1	1	13	14	16
57	Oct. 11–30.....................	1	5	27	1	70	7	......	......	52	5	1	4	149	18
	Nov. 1–12 (11 days)......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
58	Nov. 13–29...................	1	5	16	1	23	4	47	1	53	4	2	2	139	14
59	Nov. 30 to Dec. 9.........	1	4	18	1	......	......	37	2	11	1	1	4	66	9
	Totals................			351	1	572	63	814	29	347	29	15	54	2084	204

The work was commenced March 23d, 1886, and continued until December 19th, 1886. This time was distributed as follows:

		Days.
Actually working,..	189	
Moving drill,...	15	
	——	204
Idle, ...		18
Holidays, ...		2
Sundays, ...		37
		——
Total,..		261

* Water short.

Table VI.

Compiled from the Daily Reports—the Time Occupied by the Different Operations being Actually or Proportionally Charged to the Quantity of Material passed through.

MATERIAL.	Work performed.				Time consumed.					Av. No. ft. Per Day,	
	Holes.		Total No. ft.	Per cent. of Material.	Moving.	Drilling.	Casing, etc.	Total.	Per cent.	Drilling Alone.	Drilling and Delays.
	No.	Average Depth.									
Clay and gravel	......	......	351	17	....	14	....	....	....	25	....
Gravel and boulders	......	......	572	27	6.5	63	54	137.5	68	9	6.7
Decomposed gneiss	......	......	814	39	6.0	29	....	35	17	28	23.1
Hard gneiss	......	......	347	17	2.5	29	....	31.5	15	12	11.1
	14	149	2084	100	15.	135	54	204	100		10.2

From the above the following is deduced :

		Daily Progress.
Hard gneiss (taken as standard unit),	1	11 to 12 ft.
Decomposed gneiss,	2 to 2.3	23.1 to 28 ft.
Clay, gravel, and boulders,	0.6 to 0.75	6.7 to 9 ft.
Clay and gravel,	2.1	25 ft.

COST PER FOOT.

Labor, Coal, etc.			
1 foreman, 243 days, 8.1 months, at $125,		$1,012 50	
1 assist. foreman, " " " " 70,		567 00	
4 men, " " " " 65,		2,206 00	
Teams, etc., moving,		80 00	
			$3,865 50
Coal, 189 days, at 607 lbs. per day—66.72 tons,			359 50
Supplies and Repairs,			
Am. Rock Drill Co.,		471 75	
Foundry,		291 50	
Lumber,		22 50	
Rope,		22 50	
Lard oil,		8 05	
			816 30
Interest on plant, $6,000 at 12 per cent., 8.1 months,			486 00
Total,			5,527 30
Replacing diamonds,		250 00	
Diamond drill lost,		300 00	
			550 00
Total, 204 days in use,			$6,077 30
Average per day,			29 79
Average per foot,			2 91

Table VII.

Cost per Foot of Drilling in Different Materials.

Material.		Total cost.		No. of feet.	Cost per foot.
Clay, gravel, and boulders,	68% × 5,527.30 =	$3,758.56		÷ 923 =	$4.07
Decomposed gneiss,	17% × 5,527.30 =	939.64		÷ 814 =	1.15
Hard gneiss and limestone,	15% × 5,527.30 =	829.10	$1,379.10	÷ 347 =	3.97
Diamonds and drill lost,		550.00			
		$6,077.30			

The items that make up the cost per foot may be divided as follows:

Labor,	70 per cent.
Coal,	7 "
Repairs and supplies,	15 "
Interest,	8 "
	100 "

As, in general practice, the holes would be probably much deeper, and the cost of labor about 20 per cent. less, the above figures may be accepted as having a liberal margin of excess.

RECAPITULATION.

Taking hard gneiss as a standard, calling it unity, we have—

	Daily Progress.	Cost per ft.
Hard gneiss,	1 = 11 to 12 ft.	1 = $3.97
Decomposed gneiss,	2 to 2.3 = 23.1 to 28. ft.	0.3 = 1.15
Clay, gravel and boulders,	0.6 to 0.75 = 6.7 to 9 ft.	1.03 = 4.07
Average,	$3.06 per foot.	

The Big Run in Shaft 15, South Heading.

In the north heading, during 9 weeks previous to this run, 567 feet were made, and some timbering was also done.

The south heading, during 10 weeks, had been advanced 730 feet, and runs of 90, 83 and 82 feet per week were made. The subsequent removal of the bench for this distance required 21 weeks. The rock was a hard, compact gneiss, with close seams and occasional streaks of quartz; the general stratification was along the axis of the tunnel. The men of their own accord decided to break the record.

No apparent preparation was made beyond obtaining a larger supply of powder. The work in the north heading had been discontinued two weeks before. The point selected for the trial was 3193 feet from the shaft and about 3400 feet from the compressor.

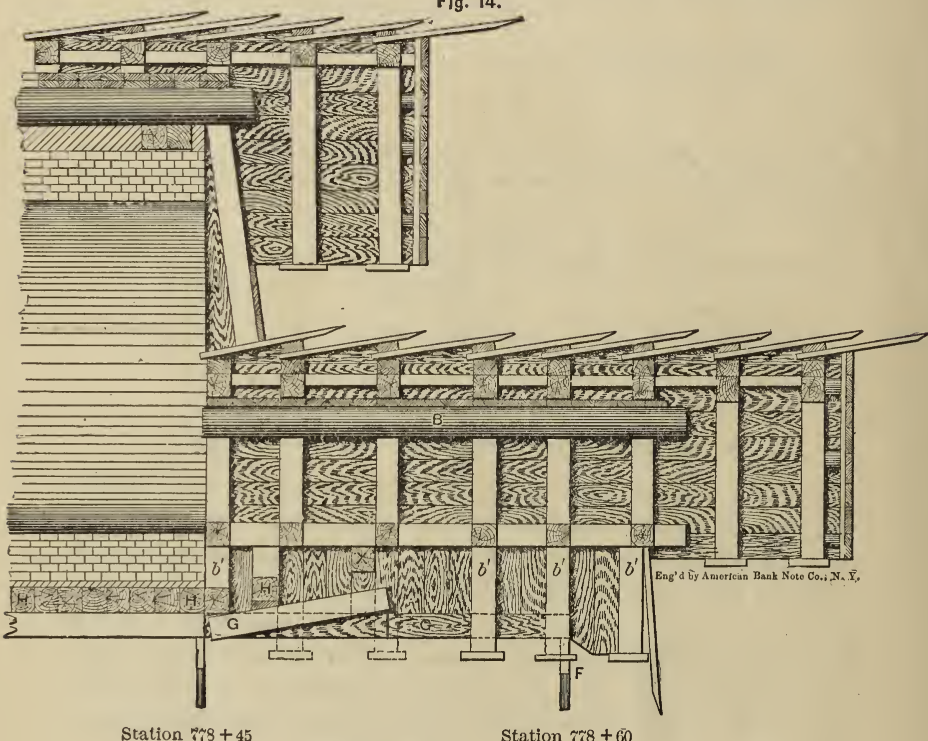
The plant consisted of one duplex Rand compressor, Class "B," supposed to deliver 1325 cubic feet per minute, at 80 pounds pressure. The air was conveyed through 5-inch and 4-inch pipe; the loss of pressure due to leaks, friction, etc., was about 15 pounds. Three Slugger drills were used.

The work was carried on continuously in nominally 10-hour shifts, with the same gang of men. One shift was lost by the men being disabled by powder-smoke.

Ordinarily the work of a 10-hour shift was divided as follows:

Mucking out, 7 to 9.30 A.M., ...	2½ hours.
Drilling from 9.30 to 4.30 P.M., ...	6 "
Charging holes from 4.30 to 5 P.M., ...	½ hour.
Firing from 5 to 6 P.M., ...	1 "
	10 hours.

Fig. 14.



Longitudinal Section of Fig. 15.

The following is the record:

1887, March 19th to 26th. Station 922 + 41 to 923 + 46.1 = 102.1 feet; area, 145.5 square feet, making the total excavation 550 cubic yards. Number of drills, 3 Sluggers.

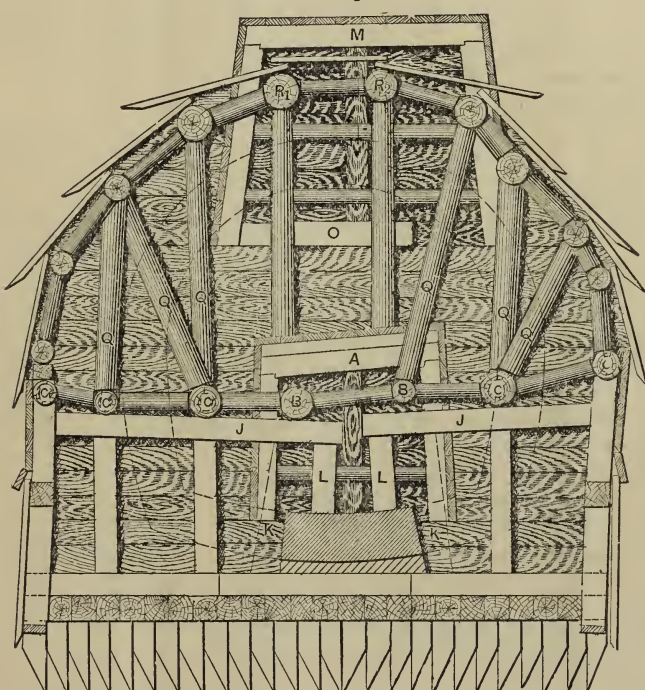
	Feet.
Depth of holes, 8 center-cut, 10 feet deep, ...	80
12 side-cut, 8 feet deep, ...	96
Total feet drilled for each blast, ...	176

Number of blasts,	13
Total feet drilled in all,	2288
Feet drilled per cubic yard,	4.16
Pounds of powder used,	2200
Pounds of powder used per hole,	8.46
Pounds of powder used per cubic yard,	4
Average advance per blast,	7.86

About 25 per cent. of the muck was left in the tunnel.

The credit of organizing and executing this work is due to the

Fig. 15.



Station 778 + 60
Scale; ⅛ in.=1 foot.

Progressive Timbering by English Method.

men themselves, who received no extra pay. The contractors claim to have lost money by the operation. The following is their statement of cost:

Shaft 15 S. Sta. 922 + 44 to 923 + 461 = 102.1 feet.

March 19*th to* 26*th*, 1887:

Area of heading,	145.5
Cubic yards of rock broken,	550.0
" " mucked out,	410.0

Labor.

		Per shift	Total for 13 shifts.	Per cubic yard.
Drilling and blasting:				
1 heading-boss,		$3.25		
3 drillers,		7.50		
3 helpers,		5.25		
1 nipper,		1.00		
1 powderman,		1.00		
		18.00	234.00	$0.42
Mucking and handling:				
1 muck-boss,		2.50		
9 muckers,		13.50		
		16.00	208 00	0.50
3 drivers and mules,		6.75		
1 trackman,		1.50		
2 sumpmen,		1.50		
		9.75	126.75	0.31
Outside labor:				
2 bellmen,		1.50		
2 topmen,		1.50		
		3.00	39.00	0.09
Power and incidentals:				
Power, 1 engineer, per week,	$15.00			
Power, 1 engine-driver, "	9.00			
Power, 1 fireman, "	12.25	36.25		
1 machinist, half-week,	7.00			
1 blacksmith, per week,	15.00			
1 blacksmith's helper, "	10.00			
1 carpenter, half-week,	7.50			
1 time-keeper, per week,	14.00			
1 electrician, half-week,	6.00	59.50		
1 general foreman, pr week,		35.00	130.75	0.24
Carried forward,			$738.50	$1.56
Sundries:				
5 tons of coal, at $5.00, 7 days,		$175.00		
Oil and candles,		12.50		
Steel,		5.00	192.50	0.35
Powder:				
2100 pounds rackarock, at 16½,		$346.50		
100 " J. L. aqueduct powder, at 16½,		16.50	363.00	0.65
			$1382.00	$2.56

Recapitulation: Cost per Cubic Yard.

Inside labor:		
Drilling and blasting,	$0.42	
Mucking	0.50	
Transportation,	0.31	$1.23

Outside labor:			
Shaft,	0.09		
Engineers, etc.,	0.07		
Incidentals,	0.11		
General foreman,	0.06	9.33	$1.56
Fuel, etc.,		0.35	
Powder,		0.65	
Interest, etc., on plant,		0.37	1.37
Total,			$2.93

Table VIII.

Log, Supplied by the Contractors, but, for Comparison, somewhat Extended.

Date.	No. of Shot.	Commenced Firing.	Time of Firing.	Time of Drilling, etc.	Total Time bet. Blasts.	No. Cars of Rock.
March 19, 1887	1	5.30 P.M.	0.50	10.30	12.00	50
" 20, "	2	6.10 A.M.	0.50	11.10	12.00	50
" 20, "	3	4.50 P.M.	1.50	9.50	14.00	57
" 21, "	4	6.30 A.M.	1.10	11.30	13.00	62
" 21, "	5	6.00 P.M.	0.30	11.00	13.00	60
" 22, "	6	6.30 A.M.	0.40	11.30	13.00	54
" 22, "	7	5.30 P.M.	0.40	10.30	13.00	66
" 23, "	8	6.10 A.M.	0.50	11.10	12.00	74
" 23, "	9	6.00 P.M.	14.10	11.00	14.10	86
		Disabled by	Powder-	smoke.		
" 24, "	10	7.00 P.M.	0.35	12.00	12.00	66
" 25, "	11	6.20 A.M.	0.50	11.20	13.00	73
" 25, "	12	5.05 P.M.	0.55	10.05	12.00	56
" 26, "	13	6.35 A.M.	0.40	11.35	12.00	66
						820*

* Equal to 410 cubic yards.

The Big Run in Shaft 16, North Heading.

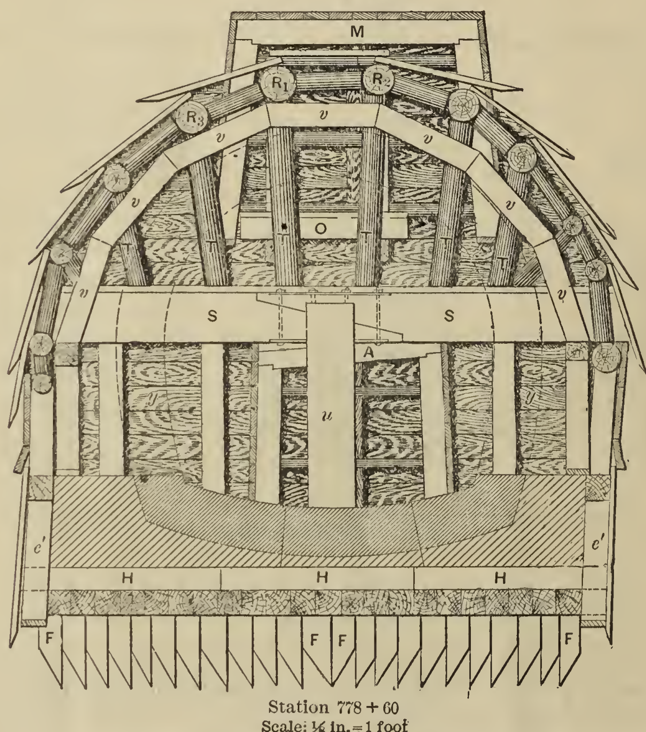
Station 930 + 16, which was 3886 feet from the shaft, was selected as a favorable point at which to make the attempt to break the record. The rock was hard, fine-grained mica-schist, free from open seams, and practically the same as that encountered 700 feet north in Shaft 15, when the big run was made there. In 10 weeks previously, the heading had advanced 469 feet.

The subsequent removal of the corresponding bench required 17 weeks. The plant was the same as that at Shaft 15, but better arranged and probably in better condition. It had been carefully overhauled, and the machinery and tools had been put in perfect order. A supply of 60 per cent. powder, made by a special formula for the occasion, was obtained. The best-trained men were engaged,

and all means known to art and force were combined for the supreme effort. The work was pushed to the utmost, not only by the foreman, but by the three sub-contractors in person, for 7 days or 168 hours; during this time an hour and 20 minutes were lost on account of the "air-tank taking fire," and two strikes of the laborers. Though the force was divided into 10-hour shifts, yet as soon as a man became exhausted he was replaced by another.

It is claimed by the sub-contractors, Messrs. Denton, Brenchard

Fig. 16.



Completion of Timbering and Setting of Invert.

and Pennell, that if they had not been impeded by the muck they could have fired another shot.

The bottom of the heading was about 3.8 feet above the spring-line. Area of heading above spring-line, 126 feet; area of bench below spring-line, 326 feet.

The following is the record:

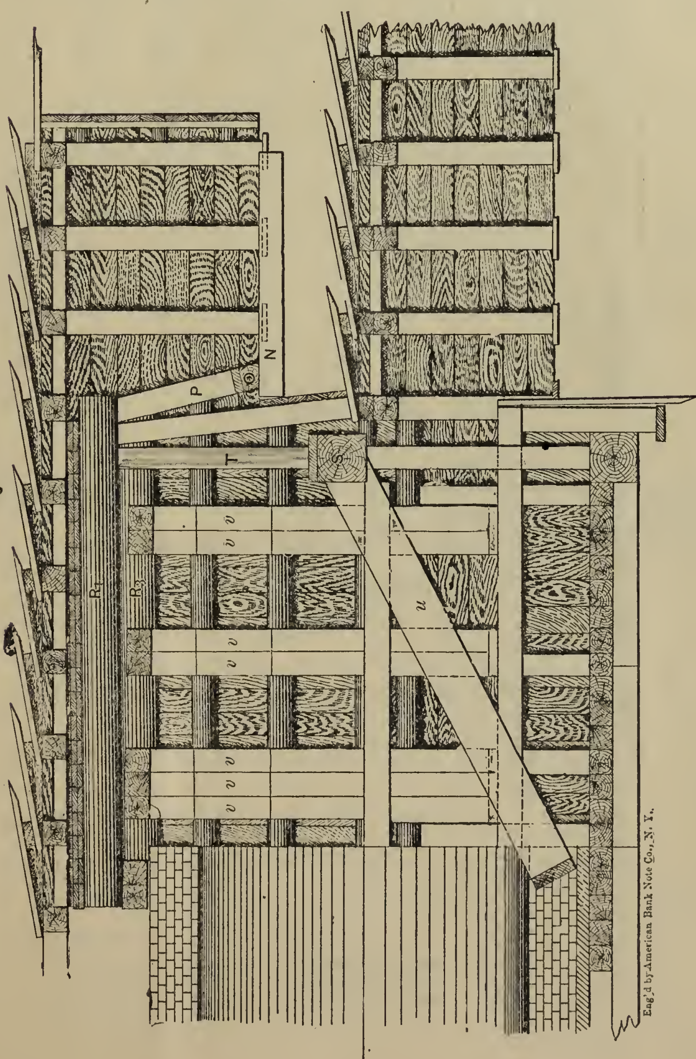
1887, July 16th to 23d. Sta. 930 + 16 to 928 + 89 = 127 feet; area 125.6; cubic yards, 591. Distance from compressor, 3965 feet.

Loss of pressure, 20 pounds. 2 Rattler drills, each using 530 cubic feet of air per minute.

		Feet.
Holes drilled per shot,	center-cut, 8 holes $8\frac{1}{2}$ feet deep,	68
	side-cut, 10 holes 8 feet deep,	80
		148

	Feet.
18 shots, 324 holes,	2664
Feet drilled per cubic yard,	4.33
Total pounds powder used,	2050
Pounds powder used per cubic yard,	3.46
Pounds powder used per hole,	6 33
Advance per blast,	7.05

Fig. 17.



Station 778 + 60

Station 778 + 45

Scale; ⅛ in. = 1 foot

Longitudinal Section through Fig. 16.

Table IX.

Log, supplied by the Contractors of Shaft No. 16.

Length, 127 linear feet. Area, 125.6 sq. feet. Cubic yards, 591.

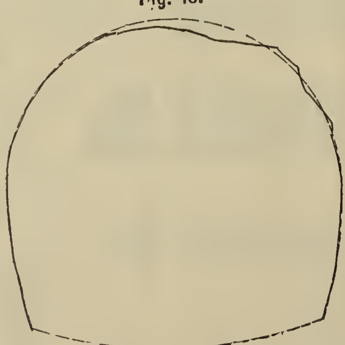
Date.	Shot.	Commenced.	Mucking.	Drilling.	Charging.	Blasting.	Clearing.	Time of Shot.
1887.			Hours.	Hours.	Hours.	Hours.	Hours.	Hours.
July 16.......	1	10 A.M.......	1.30	5.00	0.30	1.30	0.30	9.00
	2	7 P.M.......	2.30	5.30	0.30	2.30	1.00	12.00
" 17........	3	7 A.M... . .	2.00	5.00	0.30	1.00	0.15	8.45
	4	3.45 P.M....	3.15	4.45	0.15	1.00	0.15	9.30
" 18........	5	1.15 A.M....	2.00	5.30	0.15	1.00	0.15	9.00
	6	10.15 A.M. ..	2.15	5.00	0.30	1.00	0.15	9.00
	7	7.15 P.M....	2.15	5.00	0.30	1.00	0.30	11.45
" 19........	8	7.00 A.M....	2.30	5.30	1.00	0.45	0.15	10.00
	9	5.00 P.M.. ..	2.30	6.00	0.30	1.00	0.15	10.15
" 20........	10	3.15 A.M.,..	2.15	4.45	0.30	1.00	0.15	8.45
	11	12.00 M.......	1.30	4.30	0.15	0.45	0.15	7.15
	12	7.15 P.M....	2.00	4.45	0.15	1.15	0.15	8.30
" 21........	13	3.45 A.M....	1.15	4.30	0.15	0.30	0.15	6.45
	14	10.30 A.M....	1.30	5.30	0.30	1.00	0.30	9.00
	15	7.30 P.M....	2.30	5.30	0.30	0.45	2.15	11.30
" 22........	16	7.00 A.M....	2.30	5.00	0.30	1.00	0.30	9.30
	17	4.30 P.M.,...	2.30	6.30	0.30	0.45	0.15	10.30
" 23........	18	3.00 A.M....	1.30	4.30	0.15	0.30	0.15	7.00
Total......	18	....	38.15	92.45	8.00	18.15	10.45	168.00
Average..	....	....	2.08	5.09	0.27	1.00	0.36	9.20

Mucking, ...	23	per cent. of time.
Drilling, ...	55	" "
Charging holes, ...	5	" "
Firing, ...	11	" "
Clearing of smoke, ...	6	" "
	100	

Number of cars of muck, 953—equal to 489 cubic yards, which corresponds to a heading-area of 104 square feet.

About 25 or 30 per cent. of the total rock broken was left in the tunnel.

Fig. 18.



Crushing of the Arch.
Station 778 + 16
Scale; ⅛ in.=1 foot.

TABLE X.

Examples of Rapid Work.

Date.	Shaft.	Time. Days.	Progress. Total Linear Feet.	Progress. Linear Feet Per Day.	Progress. Linear Feet Per Blast.	Progress. No. cub. yds.	Drilling. No. of Drills.	Drilling. Nr. Holes to Blast.	Drilling. Av. Depth of Holes.	Drilling. Total Feet Dril'd.	Drilling. Ft. of Holes Per Cubic Yard.	Powder. Total p'nds. Used.	Powder. Lbs. to Hole.	Powder. Pounds to Cubic Yard.	Remarks.
June, 1886......	23 N	22	254.5	11.52	......	......	4	......	......	......	......	......	......	......	Heading, 14 x 14 Feet.
" "	23 S	26	265.5	10.21	......	......	4	......	......	......	......	......	......	......	" "
1887.															
Jan. 3 to Feb. 1......	15 S	24½	288.0	11.75	......	......	2	......	......	......	......	......	......	......	" 8 x 16
Jan. 8 to Mch. 12...	15 N	54	567.0	10.05	......	......	3	......	......	......	......	......	......	......	" "
" " " " ...	15 S	60	730.0	12.16	......	......	3	......	......	......	......	......	......	......	" "
Mch. 19 to 26......	15 S	65	102.1	15.07	7.86	550	3	20	8.8	2288	4.16	2200	8.46	4.00	" 9 x 17
May 7 to July......	16 N	60	469.0	7.81	......	......	......	......	......	......	......	......	......	......	" 9 x 16
July 16 to 23......	16 N	7	127.0	18.14	7.05	5.91	2	18	8.25	2564	4.33	2050	6.33	3.46	" 9 x 16
1888.															Bench.
Mch. 31 to May 19	15 S	42	577.0	6.85	......	3360	2	4	9.00	4788	1.04	7500	5.06	2.23	Worked from both ends.
Dec. 3 to Mch. 24	16 S	102	594.0	5.82	......	......	1	......	......	......	......	......	......	......	Worked at one end.

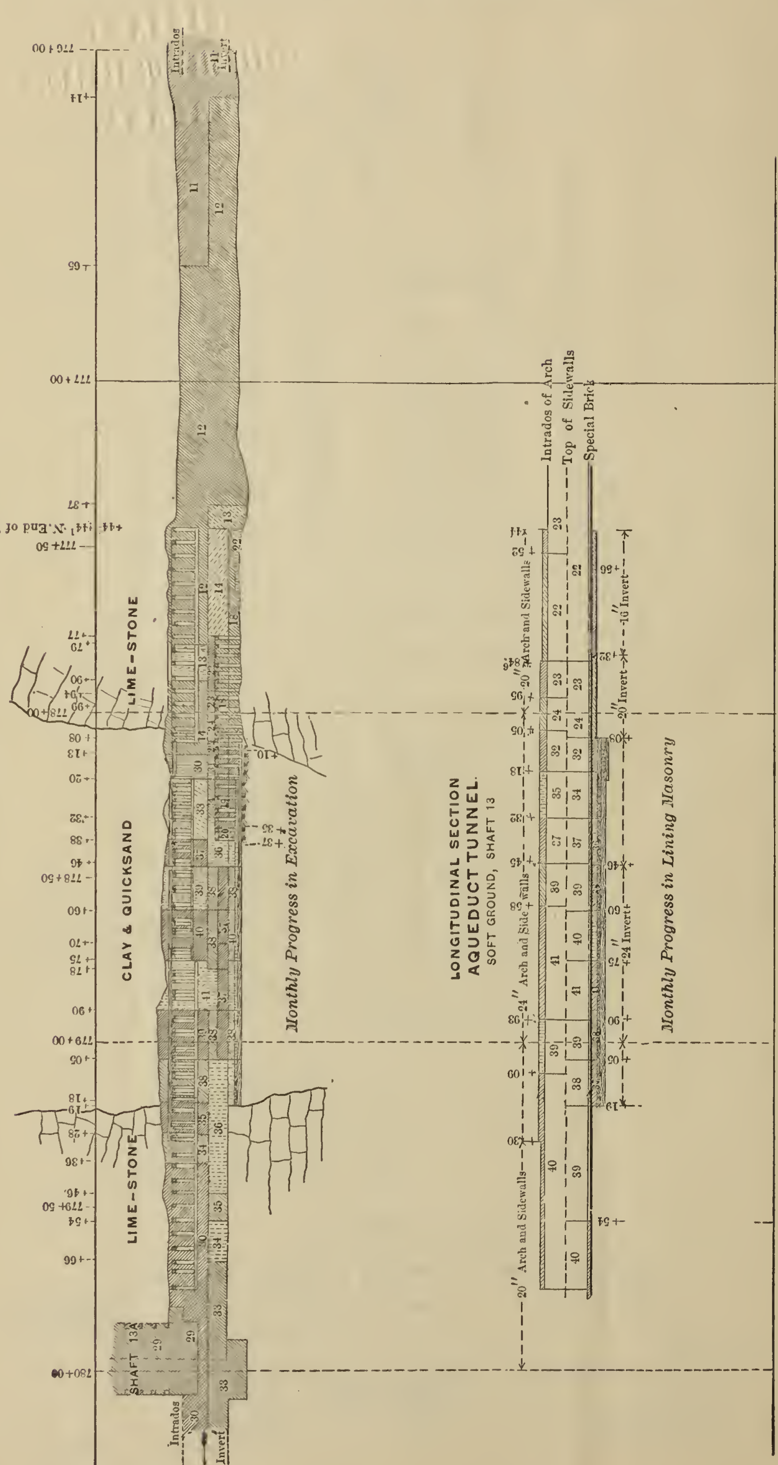
COST OF DRIVING.

Average Cost of Driving a Single Heading.

Progress, 47 feet. Area, 15 square feet. Cu. yds., 183.

	Per shift.	For 14 shifts.		Per cubic yard.
Inside labor:				
Drilling and blasting, .	$18.00	$252.00		
Mucking, ...	16.00	224.00		
Transportation, . . .	9.75	136.50	$612.50	$3.34

Fig. 19.



Sections showing Rate of Progress.

Outside labor:				
At shaft, ...	3.00	42.00		
Engineers, etc., . .		130.75		
			172.75	0.94
Coal, etc, 3 tons per diem, ...			122.50	0.67
Powder, 550 pounds at 16½, ...			90.75	0.50
Interest, etc., on plant, ...				0.37
				$5.82
By driving two headings at the same time, the outside labor and superintendence will be one-half, reducing the above amount, . .				0.50
Total, driving two headings at once, ...				$5.32

Average Cost of Excavating Bench.

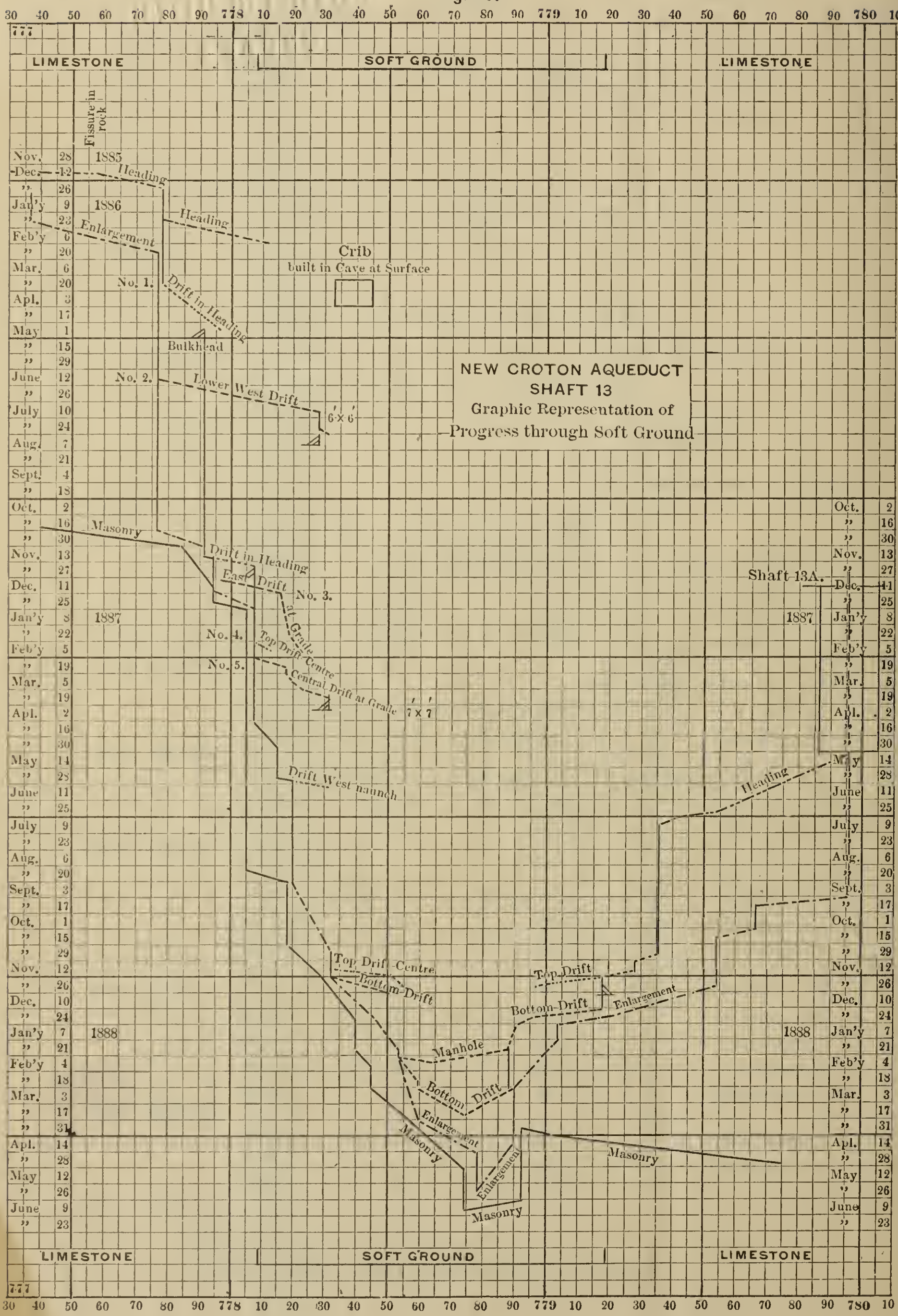
Sta. 921 + 33 to Sta. 927 + 00 = 577 feet. Area 167.41, Cu. yds., 3578.
April 2d to May 19th, 1888 = 48 days.

Broken, ... 3578 cu. yds.
Mucked out, ... 3360 "

						Per cubic yard.
Drilling and blasting:						
1 boss, ...	$70.00 per month,	77. shifts,	$179.41			
1 drill-runner, . .	2.50 per diem,	157.5 "	393.75			
1 drill-helper,* . .	1.75 "	139.9 "	244.82			
1 nipper,* . . .	1.00 "	85.5 "	85.50			
1 powderman, . .	2.00 "	46.0 "	92.00			
				$995.48		$0.28
Mucking and transportation:						
1 boss, ...	70.00 per month,	84. shifts,	195.72			
15 muckers,* . . .	1.50 per diem,	1553.3 "	2329.95			
				2525.67		0.75
1–2 drivers and mules, .	2.25 per diem,	144.6 shifts,	325.35			
1 trackman,* . . .	1.50 "	54.5 "	81.75			
2 dumpmen,* . . .	1.50 "	171.6 "	257.40			
				664.50		0.20
Outside labor:						
1 bellman,* . . .	1.75 per diem,	146.2 shifts,	255.85			
1 sumpman,* . . .	1.75 "	52.4 "	91.70			
1 topman, . . .	1.50 "	149.6 "	224.40			
				571.95		0.17
Hoisters, extra, . .	2.00 "	92.		184.00		0.05
2 engineers, . . .	2.50 per diem,	96. shifts,	240.00			
1 engineer, . . .	2.00 "	48. "	96.00			
2 firemen, . . .	1.75 "	92. "	161.00			
1 pumpman, . . .	1.75 "	48. "	84.00			
				581.00		0.17
1 machinist, . . .	2.25 per diem,	46. shifts,	103.00			
1 blacksmith, . . .	2.50 "	47. "	117.50			
1 helper, ...	1.50 "	48. "	72.00			
				292.50		0 09

* Muckers were often used to replace other men.

Fig. 20.


NEW CROTON AQUEDUCT
SHAFT 13
Graphic Representation of
Progress through Soft Ground
LIMESTONE
SOFT GROUND
LIMESTONE
Fissure in rock
1885
1886
1887
1888
Heading
Enlargement
Crib
built in Cave at Surface
No. 1.
Drift in Heading
Bulkhead
No. 2.
Lower West Drift
6 x 6
Masonry
Drift in Heading
East Drift
No. 3.
No. 4.
No. 5.
Top Drift Centre
Central Drift at Grade
7 x 7
Drift West haunch
Shaft 13A.
Top Drift Centre
Bottom Drift
Top Drift
Bottom Drift
Enlargement
Manhole
Bottom Drift
Enlargement
Masonry
Enlargement
Masonry
Masonry

Sundries,			
3 tons of coal per day, at $5.00 per ton, 48 days,	720.00		
Oil, candles, and steel, at $2.00 per diem, 48 days,	96.00		
	———	816.00	0.23
Powder:			
200 pounds forcite, at 40 cents per pound,	80.00		
7300 pounds John L. aqueduct powder, at 16½ cents,	1204.50		
27 bunches exploders, at 40 cents per bunch,	10.80		
16 spools wire, at 50 cents per spool,	8.00		
	———	$1303.30	0.38

Total number of shots fired, 133; missed, 14.

Depth of holes, 9 feet.
Number of holes, 532. 4788-

Recapitulation: Cost per Cubic Yard.

Inside labor:			
Drilling and blasting,	$0.28		
Mucking,	0.75		
Transportation,	0.20		
	——	$1.23	
Outside labor:			
At shaft,	$.17		
At shaft, extra,	.05		
Engineers, etc.,	.17		
Incidentals,	.09		
	——	0.48	$1 71
Fuel and sundries,			0.23
Powder,			0.38
Interest, etc., on plant,			0.37
			——
Total cost per cubic yard,			$2.69

Muck left in tunnel, 6 per cent.

Cost of Driving Heading and Bench Together.

Linear feet = 30. Area = 283 square feet. Cu. yds. = 314.

			Per cubic yard.
Inside labor, heading, 120 yds., $3.46	$415.20		
" bench, 194 yds., $1.23,	238.64	$653.84	$2.08
Outside labor,	$244.25	.78	
Coal and sundries,	192.50	.62	1.40
Powder, 124 cy. (3 pounds at 16½) $.50,	$62.00		
" 190 cy. (2.3 pounds at 16½), $.38,	73.72	135.72	.44
			——
Total,			$3.92
Working two headings at same time,			$3.22

The above figures are submitted as an approximation to the truth. Acknowledgments are due to Mr. Joseph F. Banks, Mr. H. C. Allen,

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